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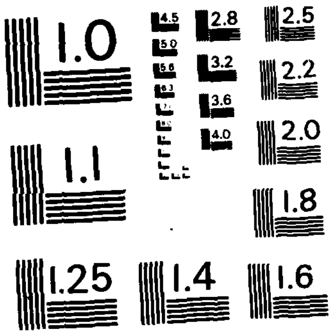

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COMPUTER APPLICATIONS TO GEOTECHNICAL ENGINEERING

A SPECIAL RESEARCH PROBLEM

Presented to

The Faculty of the School of Civil Engineering

Georgia Institute of Technology

by

Dana Kevin Eddy

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Civil Engineering

August 1983

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GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
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A very Good Report
R D Barksdale

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Above all, I praise the Heavenly Father for his guiding light. For without his gifts of perserverance and knowledge, this work would have never been completed.

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ABSTRACT

This report presents four geotechnical engineering programs for use on personal computing systems. An Apple II-Plus operating with DOS 3.3 Applesoft language was used. The programs include the solution of the signpost problem, the cantilevered sheet pile problem, the slope stability problem, and the flexible pavement design program.

Each chapter is independent and does not rely upon theories or data presented in other chapters. A chapter outlines the theory used and also presents a users guide, a program list, and verification of the program by hand calculation.

This report assimilates the product a practicing engineer would expect to receive when procuring software services.

CHAPTER I

INTRODUCTION

Micro-computers are rapidly becoming the work-horse of the small business and engineering world. All types of businesses are finding the micro-computer an invaluable tool. Uses range from cost accounting to word processing to an engineering calculating machine. The key advantages of personal computers over previous methods are its easy access, speed, reliability, and accuracy.

Engineering firms whose availability to main frame computing facilities have been limited by economics or demographics can now acquire personal computers and software for a fraction of the capital outlay. Software can be designed to fit the precise needs of the firm whereas firms used to cater their needs around an established software base. This is especially advantageous to specialized firms whose services demand repetitive engineering problems. Rather than expending labor on iterative problem solving, a personal computer matched with properly designed software can now provide engineering solutions at a fraction of the cost.

The introduction of the personal computer into the engineering firm provides a domino effect. The time which was once expended on iterative problem solving can now be devoted to more productive activity such as consideration of more complex problems and bidding strategy. Accordingly, the small engineering firm can now bid more jobs, accomplish more work and subsequently, increase the firm's net worth. It is becoming commonplace for short and long-range business plans to include the purchase and use of personal computers.

The personal computer is a godsend to the geotechnical engineer. Due to the nature of soil, the engineer is constantly dealing with lower and upper bounds of possible problem solutions. Unlike concrete and steel, soil has variable engineering properties and cannot be relied upon to perform in a consistent manner; consequently, the engineer must consider several possible combinations of soil behavior in order to provide a safe design. Once the soil characteristics have been normalized, the engineer uses mechanics of particulate matter to best approximate the response and behavior of soil acted upon by external forces and natural phenomena such as flow of water through the medium under a hydrostatic head.

At this point, the personal computer comes into play. The computer will calculate quantities and values according to a predetermined sequence. If the same imput variables

are used, the computer will calculate identical values and quantities. The engineer then varies the input variables according to his evaluation of the possible conditions that may exist for a particular problem. The output will then represent a range of expected behavior of which the engineer will use for his design. Problems such as calculating the required penetration of a cantilevered wall can take up to four hours to calculate. This time represents several calculation iterations with one particular set of soil data. If no math errors were made, one possible bounding answer would be established. The same procedures would be repeated to establish another bound. Two trial boundary conditions have been established, but what if intermediate values are not linearly related to the boundary values? The prudent engineer would make intermediate value calculations. The time involved can be enormous. The personal computer can calculate iterative problems in a fraction of the time required to hand calculate the problems and without the math errors associated with hand calculations.

The scope of this special report is to program several iterative problems of interest to geotechnical engineers. The programs includes the calculation of the required depth of a vertical post subjected to lateral loads (SIGNPOST 1), the required penetration of a cantilevered wall (CANTWALL 1), and the design of flexible pavement (AASHTO 1). Additionally,

a slope stability program was translated and modified by the author (BISHOP 1).

No report of this nature would be complete without a warning about the ignorant use of computing software. Two major problems, separate or combined, can render the software and subsequent solutions totally useless. The user must understand the problem that the software is presumed to solve. In general, there are several methods or algorhythms that can be used to solve engineering problems, but each method is best suited for a particular variation; furthermore, the solutions can significantly vary from one method to another. This is particularly evident with dynamic pile driving formulas. The user must understand the use and limitations of the program software. Although the user may understand the problem and its methods of solution, an erroneous entry or a program option inadvertently exercised can invalidate the computed solution. The solution should be scrutinized against past experience and sound engineering judgment. As a final check, a hand calculation of the final solution should be made. If the user allows the computer to perform the iterations and hand checks the final iteration, the user can be assured as to the validity of the computed solution.

It is the author's intent to convey a concise description of the software's use and limitations. It would behoove the

user to become completely familiar with the text prior to basing an engineering design on the calculated solutions. This is imperative where the possible loss of life is involved.

CHAPTER II

SIGNPOST PROBLEM

2.1 Problem Definition

The computer program "SIGNPOST 1" calculates the minimum safe embedment of a cantilevered pole subjected to lateral overturning loads. Figure 2.1 defines the input variables and general geometry of the problem. Plastic theory is utilized, thus considerable deflections are anticipated. All loads are laterally applied to the pole; overturning moments are resisted by passive earth pressure.

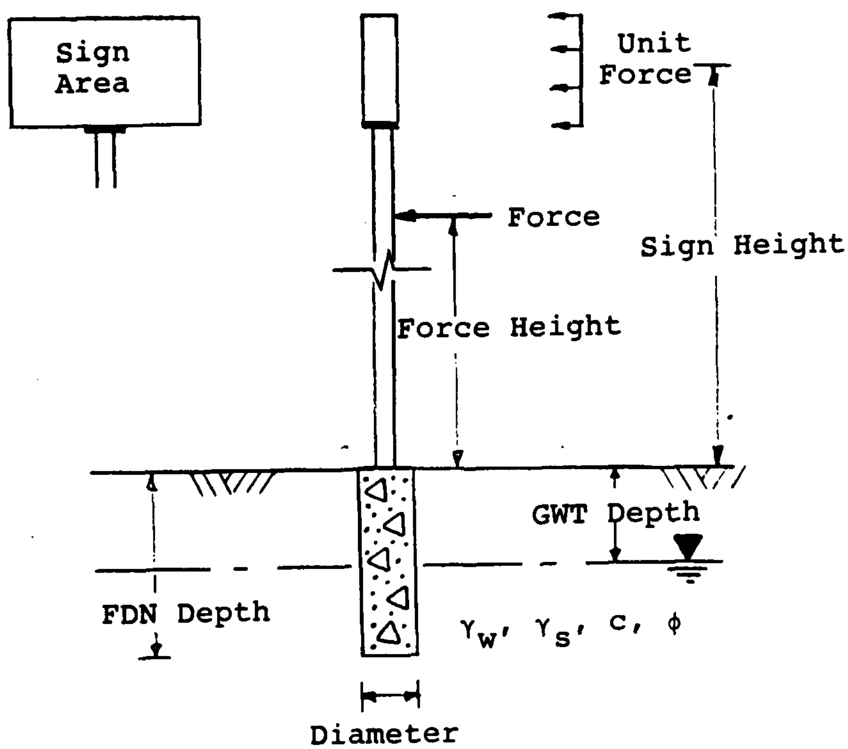

Figure 2.1. General Problem Definition.

2.2 Background Theory

Development of the laterally loaded cantilevered pole problem was initiated by J. F. Seiler in cooperation with the American Wood-Preservers' Association in the early 1930's [1]. Seiler correctly diagrammed the earth pressures about the embedded pole (Figure 2.2).

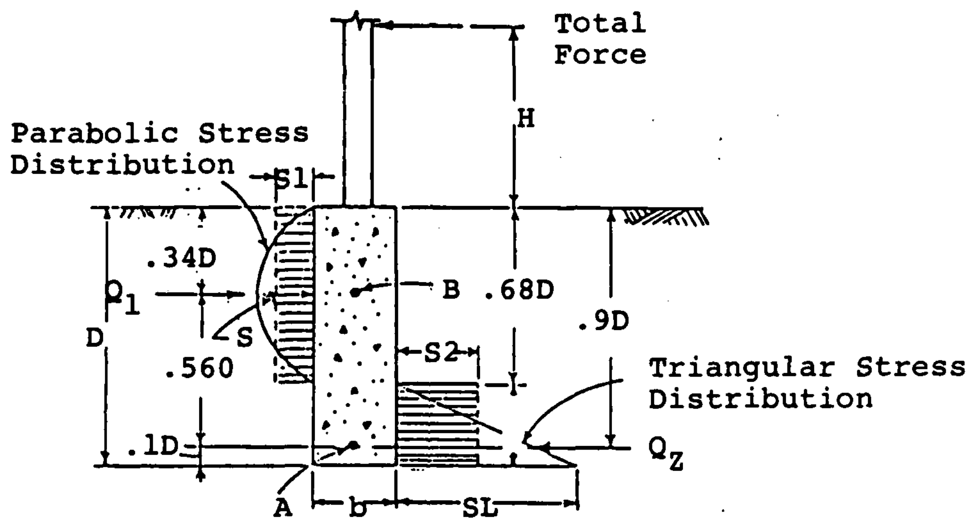

Figure 2.2. Stress Distribution on Foundation [3].

Seiler's objective was to classify embedment depths for particular timber pole classes, as industrial demand was increasing and the association felt an economic need existed for the correlation between pole class and required embedment. Timber poles are classified according to the strength in bending; Class 1 being the strongest, Class 6 the weakest in bending.

Seiler began his research on the premise that a particular pole class was best suited for a particular soil type. The most economic use of timber coupled with decreased labor of excavation lead to the conclusion that if a proper pole was used, it would develop its full bending strength just prior to soil failure. This conclusion is rational and warrants further investigation. Seiler, like many engineers, was unclear of the definition of soil failure. Although he properly perceived the earth pressure diagrams, Seiler's analysis focused on pole rotation when laterally loaded and ignored the soil pressures mobilized by the pole rotation.

A majority of the equations developed by this premise are contingent upon the angle of rotation the pole would undergo when laterally loaded. Although indirectly, Seiler was alluding to plastic theory, but allowed his stress analysis to go beyond the stress which would cause plastic failure. His analysis never made its debut in the engineering literature. Seiler adequately described the earth pressures and respective depths about the embedded pole.

In the early 1940's, Professor P. C. Rutledge was requested to devise a system by which embedment depths for signposts could be estimated. In association with the Outdoor Advertising Association of America, Professor Rutledge devised the nomograph as presented in Figure 2.3 [2].

Chart for Embedment of Posts

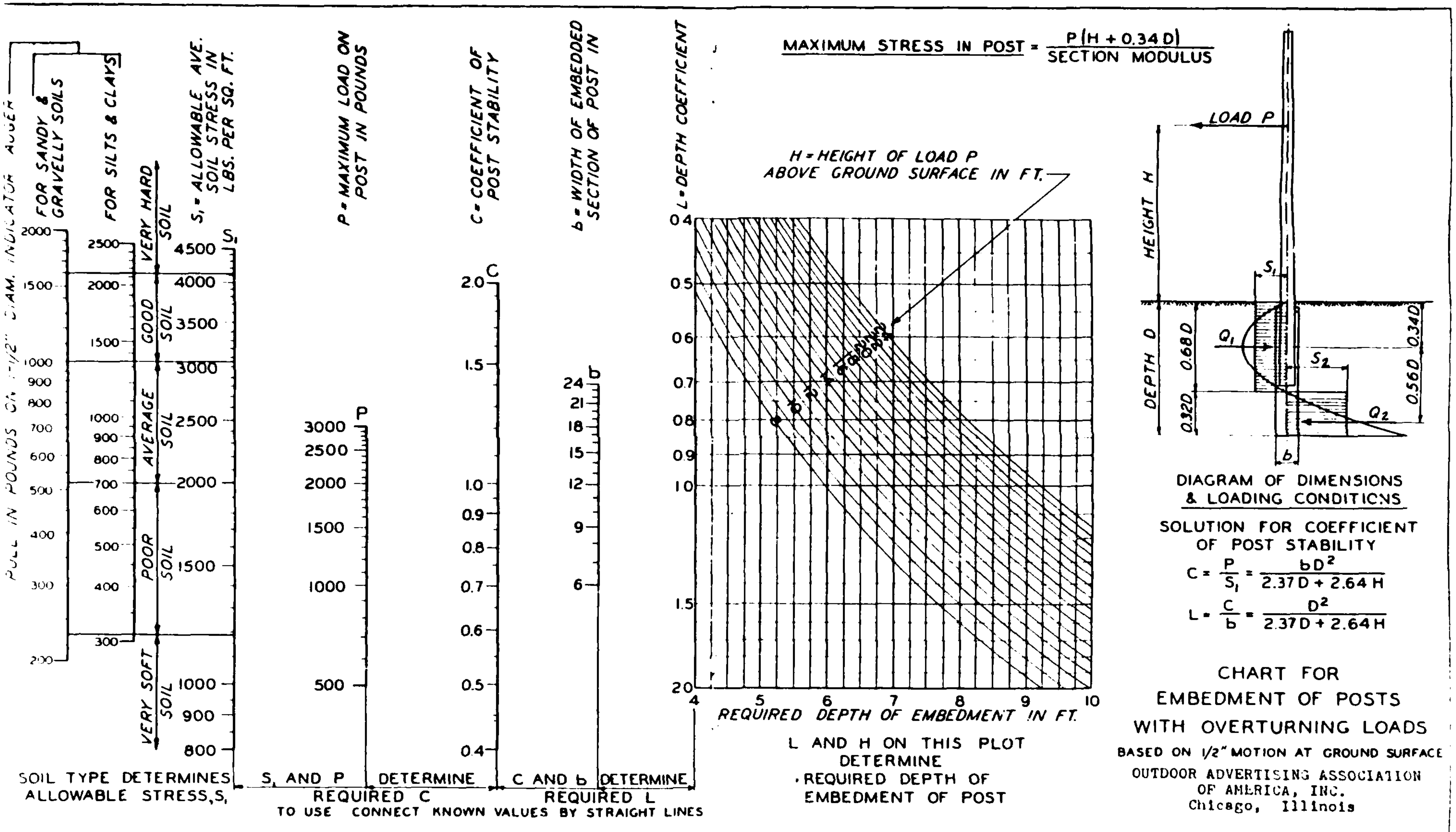

Figure 2.3. Nomograph for Pole Embedment [2].

The basis of this nomograph was the earth pressure stress distribution as presented by J. F. Seiler (Fig. 2.2). By summing forces horizontally and summing moments about Q_1, Rutledge developed the equation:

$$\frac{P}{S_1} = \frac{D^2B}{2.37D + 2.64H}$$

and solving for D in the quadratic equation:

$$S_1BD^2 - 2.37PD - 2.64PH = 0$$

$$D = \frac{2.37P + \sqrt{(2.37P)^2 + 4 \times 2.64PHS_1B}}{2\ S_1B}$$

where,

D = embedment depth (ft)

P = lateral load (#)

S_1 = average passive soil pressure (#/ft^2)

H = height of P above grade (ft)

B = diameter (ft)

S_1 is dependent upon depth as it is the passive soil resistance at .34D; thus, the above equation must be iterated.

To calculate a safe embedment depth, the soil pressure depths presented by Seiler and later used by Professor Rutledge were corroborated by Professors W. L. Shilts,

L. D. Graves, G. F. Driscoll of Notre Dame University and by Dr. J. O. Osterberg of Northwest University [2].

Due to the limited ability to test soils, and the lack of standardized soil classification, Rutledge devised a testing device which could be used to determine the in-situ average soil pressure (S_1) [2]. It consisted of a 1-½" hand auger which after being rotated into the soil would be pulled up. The force required to pull out the auger was correlated to S_1 (Figure 2.3). A scale for cohesionless soils and a scale for silts and clays are provided. The nomograph is limited to embedment depths of 10', post diameters of 6" to 24" and a load height of 24'. The above equation must be used for any parameters beyond these boundaries.

In 1957, D. Patterson, being dissatisfied with Rutledges' soil test method, modified the nomograph to include five general soil type categories; i.e., very soft, poor soil, average soil, good soil, and very hard soil [2]. To augment this general classification, the following table was also provided:

Table 2.1. Generalized Soil Classifications.

Clay, in lumps, dry	Poor soil
Clay, damp, plastic	Poor soil
Clay and gravel, dry	Average soil
Clay, gravel and sand, dry	Average soil
Earth, loose, perfectly dry	Average soil
Earth, packed, perfectly dry	Average soil
Earth, loose, slightly moist	Average soil
Earth, packed, more moist	Very hard soil
Earth, soft flowing mud	Very soft soil
Earth, soft mud, packed	Poor soil
Gravel, one inch and under, dry	Good soil
Gravel, two and one-half inches and under, dry	Average soil
Sand, clean and dry	Average soil
Sand, river, dry	Average soil

Patterson contended that in the absence of better soil data the above table would yield satisfactory embedment depths.

In an effort to refine the soil data input, D. L. Ivey and L. Hawkins [3] applied Rankine's formula for passive soil resistance:

$$Pp = \gamma z N_\phi + 2c\sqrt{N_\phi}$$

$$N_\phi = \tan^2 (45° + \phi/2)$$

With this formula, S_1 can be calculated using soil strength data, C and ϕ; furthermore, introduction of a ground water table with subsequent bouyant forces can be accounted for.

Ivey and Hawkins extended the design process to include checking the lower stresses (S_2 & SL) against the allowable stresses calculated by Rankine formula. This is especially critical when the ground water table is at or near 0.68D as the lower allowable stresses will be reduced. Ivey and Hawkins recommended applying a safety factor to the design by dividing the ultimate passive resistance by a factor of safety prior to checking the working stresses (S1, S2, and SL).

2.3 Programming Rationale

The ultimate purpose of "SIGNPOST 1" is to provide the user a design depth capable of resisting a specified lateral load. The "Rutledge" method is used as modified by Ivey and Hawkins as described in Section 2.2. The program is user oriented in that all input is prompted by clear, concise questions displayed on the monitor prior to the appropriate input command. Output format is intended to provide easy identification of the calculated solutions and supplemented by intermediate values calculated during the program routine. The flow chart, Figure 2.4, is provided as a skeleton of basic routines and conditionals as well as the general sequence of events performed between the input of the problem parameters and the printed output.

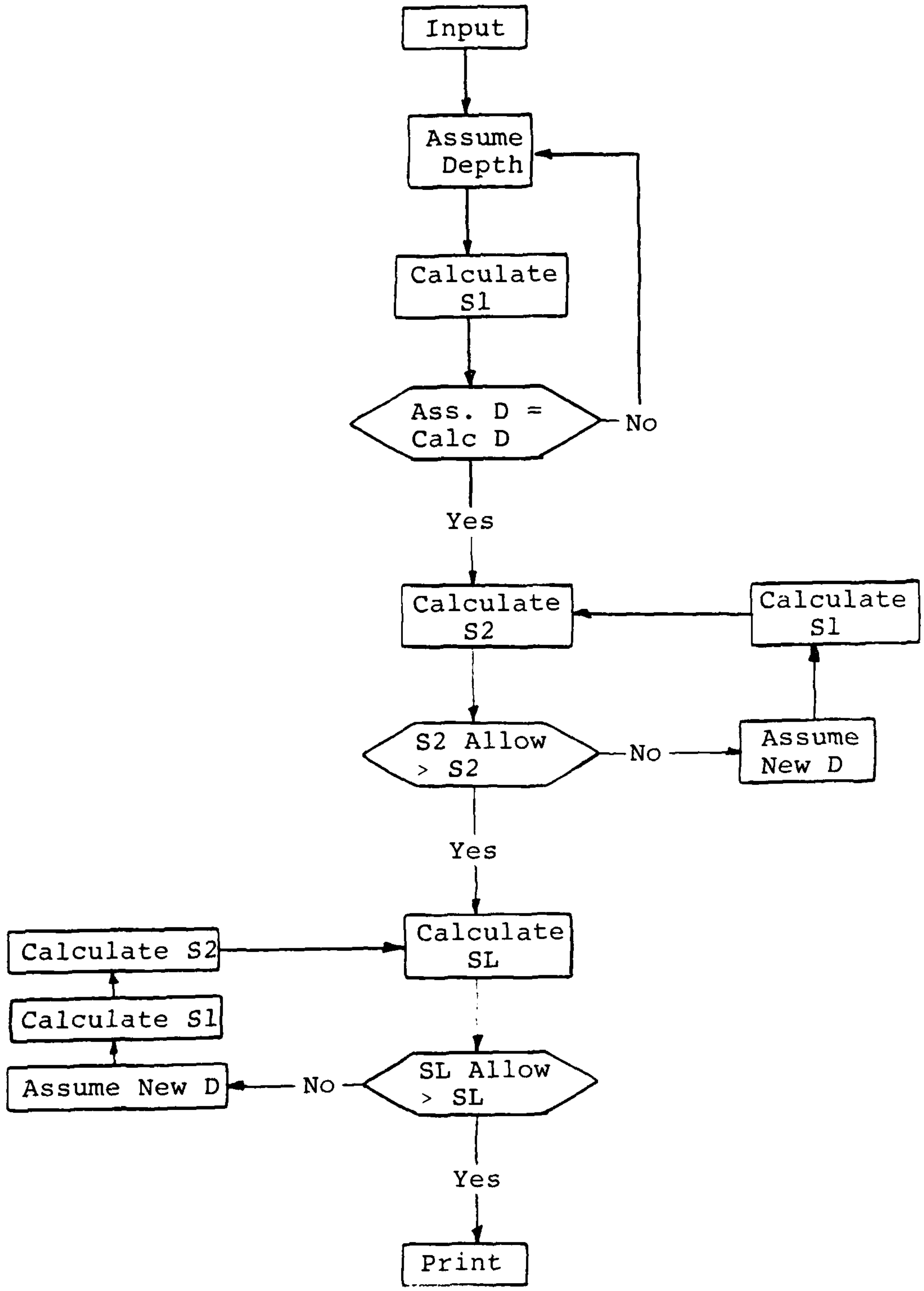

Figure 2.4 Simplified SIGNPOST1 Flow Chart.

2.4 Program Use and Limitations

2.4.1 General

"SIGNPOST 1" was programmed on an Apple II-Plus with 64K random access memory. The disk operating system was version 3.3 (DOS 3.3). Prior to using this program, the user should be familiar with the system control features of the Apple II-Plus. Namely, the user needs to know how to LOAD, RUN and use the return key; all other commands and options are integrated into the program.

As with any computer run, the user should have reviewed the required input parameters and have them available (preferably in order of response) prior to running the program. If more than one set of input parameters are to be used, it is recommended that a table be set up to prevent erroneous input and reduce input time.

2.4.2 Input

The following is a list of input parameters for SIGNPOST 1:

a) number of runs
b) angle of internal friction (degrees)
c) cohesion (PSF)
d) wet soil weight (PCF)
e) saturated soil weight (PCF)
f) wind pressure (PSF) (see Fig. 2.5)
g) height to sign centroid (ft)
h) sign area (SF)
i) post load (#)
j) ground water table depth (ft)
k) number of diameters

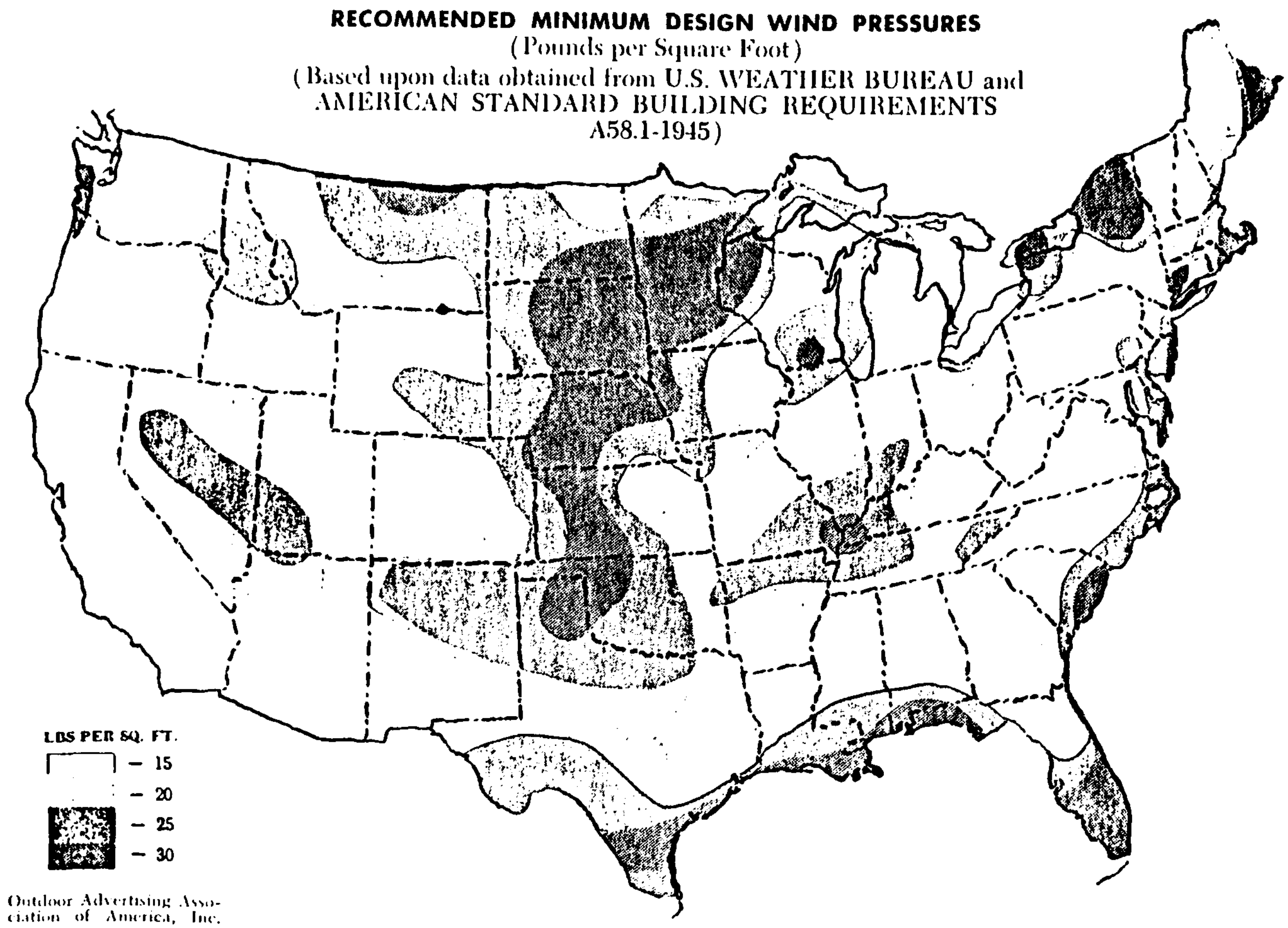

Figure 2.5. Recommended Minimum Design Wind Pressures[2].

k_1) diameter #1 (ft)
k_2) diameter #2 (ft)
k_i) diameter #i (ft)
l) safety factor
m) depth calculation tolerance
n) passive coefficient of earth pressure*

*Note: This quantity can be input or the program can calculate the passive coefficient of earth pressure at the option of the user.

2.4.3 Apple II Start Up

A brief discussion of the steps required to run a program on the Apple II-Plus will be provided here.

a) Plug the computer and the monitor into any 110v, 60 Hz, power outlet.

b) Turn the computer on by flipping the switch located on left back side to the on position. Hit the "reset" key to stop the disc drive from turning.

c) Turn the monitor on by pulling out the brightness control.

d) Insert the system master diskette into disk drive #1.

e) Type PR#6.

f) After the disk drive stops (light off) and the blinking cursor appears, remove the system master diskette.

g) Insert the slave diskette with the program to be run into the disk drive.

If the user is unsure about this procedure, refer to the operation manuals provided with the computer.

If a printer is attached to the computer type RUN SIGNPOST 1. Include a space between RUN and SIGNPOST and a space between SIGNPOST and 1. Type the return key. If a printer is not available, the user must type LOAD SIGNPOST 1. Once the flashing cursor appears, type DEL 1080, 1080. This will delete a DOS command which switches the output to the printer. Type RUN.

2.4.4 Program Use

An introduction will begin; the last line will be the first user question. See Section 2.7 for listing of all introductory statements, user prompting questions, user option questions, and output.

Each run is associated with a particular set of input data. Within each run the user may specify up to a maximum of ten diameters for which a required embedment depth will be calculated. Refer to Section 2.7 for an example. This allows the user to observe the change in required depth associated with a change in post diameter without having to repetitiously input the bulk of the input data.

SIGNPOST 1 allows the user to input an additional load on the post (see Figure 2.1). Rutledge's depth equation was modified to include an additional load and moment arm.

$$D = \frac{2.37(P+P_1) + \sqrt{(2.37(P+P_1)^2 + 4 \times 2.64(PH+P_1H_1S_1B}}{2S_1B}$$

A practical use of this feature involves considering wind pressure against wide portions of the cantilevered post. The user must input force and height (Figure 2.1). If no force is to be included, the user should input zero for both force and height.

SIGNPOST 1 provides the user the option to input the coefficient of passive earth pressure or the program can calculate the coefficient. Rankine's formula is used.

$$K_p = N_\phi = \tan^2(45 - \phi/2)$$

The user may know from experience the value of the coefficient K_p and may want to input it rather than have it calculated. The computer will ask the user which option the user desires. If the user responds to input the coefficient, the computer will respond with the question, "What is KP?" The user should at that time input the desired coefficient of passive earth pressure.

All data must be input in units of degrees, pounds, and feet. In order to change the units, the unit weight of water must be changed in line 5030 from 62.4 PCF to whatever units are to be input. The output will be in terms of the new unit, but the print statement will still print out degrees, PCF, etc. behind the variables and solutions.

2.4.5 Output

Refer to Figure 2.2 for interpretation of the output data. S is the maximum pressure of the parabolic stress distribution on the upper 2/3 of the embedded post. S1 is the average pressure of the parabolic stress distribution. S2 is calculated from S1 and represents an average stress on the lower 1/3 of the embedded post. S2 is compared to S2 ALLOW to insure that it is less. S2 ALLOW is calculated from Rankine's formula of earth pressure. SL is the maximum pressure mobilized at the bottom of the embedded post. SL is a function of S2, thus a function of S1. SL ALLOW is calculated by Rankine's formula of earth pressure but unlike S2 ALLOW, the safety factor is taken to be one. Ivey and Hawkins [3] contends that due to local plastic failure at the butt of the post, the stress would distribute upward; thus, the ultimate pressure versus the safe pressure should be used for comparison.

Following the output of the calculated data, a list of the input data will follow. This list will serve as a verification of proper data input as well as a record of data used to produce the calculated output.

2.5 Program List

```
5  SPEED= 150
10  PRINT "        **********"
11  PRINT "        *SIGNPOST*"
12  PRINT "        **********"
13  PRINT
14  PRINT
15  PRINT
20  PRINT "DANA K. EDDY, 578-80-8378"
22  PRINT "GA. INSTITUTE OF TECHNOLOGY"
24  PRINT "SCHOOL OF CIVIL ENGINEERING"
26  PRINT "DEPARTMENT OF GEOTECHNICAL ENGINEERING"
30  PRINT
31  PRINT
32  PRINT
35  PRINT "SYSTEM HARDWARE: APPLE II PLUS (64K)"
37  PRINT "SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE"
39  PRINT "PROGRAM DATE: APRIL, 1983"
42  PRINT
43  PRINT
44  PRINT
45  PRINT
50  PRINT "SIGNPOST ESTIMATES THE MINIMUM EMBEDMENT DEPTH OF A SINGLE CANT
    ILEVERED POST FOUNDATION.  THE CLASSICAL APPLICATION IS A SIGN OR MAR
    QUE SUBJECTED TO WIND LOADS."
51  PRINT
52  PRINT
53  PRINT
100  SPEED= 255
320  PRINT "HOW MANY PROBLEM SETS DO YOU WANT TO RUN?  THE USER MAY INPUT
     SEVERAL POST DIAMETERS PER PROBLEM SET."
330  INPUT N
331  PRINT
332  PRINT
340  DIM A(N,28)
350  FOR I = 1 TO N
360  PRINT "WHAT IS THE ANGLE OF INTERNAL FRICTION OF THE SOIL FOR RUN #"I
     "? (DEGREES)"
370  INPUT A(I,1)
380  PRINT "WHAT IS THE COHESION OF THE SOIL FOR RUN #"I"? (PSF)"
390  INPUT A(I,2)
400  PRINT "WHAT IS THE WET WEIGHT OF THE SOIL FOR RUN #"I"? (PCF)"
410  INPUT A(I,3)
420  PRINT "WHAT IS THE SATURATED WEIGHT OF THE SOIL FOR RUN #"I"? (PCF)"
430  INPUT A(I,4)
440  PRINT "WHAT IS THE WIND PRESSURE AGAINST THE SIGN FOR RUN #"I"? (PSF)
     "
450  INPUT A(I,5)
```

```
460  PRINT "WHAT IS THE HEIGHT ABOVE GRADE TO THE CENTROID OF THE SIGN FOR
      RUN #"I"? (FEET)"
470  INPUT A(I,6)
480  PRINT "WHAT IS THE AREA OF THE SIGN FOR RUN #"I"? (SF)"
490  INPUT A(I,7)
500  PRINT "WHAT IS THE LOAD ON THE POST FOR RUN #"I"? (POUNDS)"
510  INPUT A(I,8)
520  PRINT "WHAT IS THE HEIGHT ABOVE GRADE OF THE POST LOAD FOR RUN #"I"?
     (FEET)"
530  INPUT A(I,9)
540  PRINT "WHAT IS THE DEPTH BELOW GRADE OF THE GROUND WATER TABLE FOR RU
     N #"I"? (FEET)"
550  INPUT A(I,10)
560  PRINT "HOW MANY POST HOLE DIAMETERS DO YOU WANT TO INPUT FOR RUN #"I"
     ?"
570  INPUT A(I,11)
580  FOR J = 1 TO A(I,11)
590  PRINT "WHAT IS DIAMETER #"J" (FEET)"
600 J = J + 12
610  INPUT A(I,J)
620 J = J - 12
630  NEXT J
640  PRINT "WHAT IS THE SAFETY FACTOR FOR RUN #"I"?"
650  INPUT A(I,12)
651  PRINT "INPUT THE TOLERANCE FOR DEPTH CALCULATION. (RECOMMEND  .5 - 1.
     0 FT)"
652  INPUT TL
660  PRINT "DO YOU WANT TO INPUT THE COEFFICIENT OF PASSIVE EARTH PRESSURE
      (KP) ,(YES), OR HAVE SIGNPOST CALCULATE KP FOR YOU (NO) ?"
670  INPUT B$:X =  ASC (B$): IF X < 84 GOTO 700
680  PRINT "WHAT IS KP?"
690  INPUT A(I,28)
695  GOTO 710
700 A(I,28) = ( TAN ((45 + A(I,1) / 2) * .01745)) ^ 2
710 A(I,11) = A(I,11) + 12
720  FOR K = 13 TO A(I,11)
730 A(I,21) = 20
740 Z = .34 * A(I,21)
750  GOSUB 5000
760 A(I,22) = PS
770 A(I,23) = .6667 * A(I,22)
780  GOSUB 6000
790  IF D < A(I,21) GOTO 820
800 A(I,21) = A(I,21) + TL
810  GOTO 740
820  IF D > A(I,21) - TL GOTO 850
830 A(I,21) = A(I,21) - TL
831 Z = .34 * A(I,21)
832  GOSUB 5000:A(I,22) = PS
```

```
833 A(I,23) = .6667 * A(I,22): GOSUB 6000
834  GOTO 820
850 A(I,24) = A(I,23) / ((.28 * A(I,21) / (A(I,6) + .34 * A(I,21))) + .5)
860 Z = .68 * A(I,21)
870  GOSUB 5000
880.A(I,25) = PS
890  IF A(I,25) > A(I,24) GOTO 960
900 A(I,21) = A(I,21) + TL
910 Z = .34 * A(I,21)
920  GOSUB 5000
930 A(I,22) = PS
940 A(I,23) = .6667 * A(I,22)
950  GOTO 850
960 A(I,26) = 2 * A(I,24)
970 Z = A(I,21)
980  GOSUB 5000
990 A(I,27) = PS * A(I,12)
1000  IF A(I,27) > A(I,26) GOTO 1080
1010 A(I,21) = A(I,21) + TL
1020 Z = .34 * A(I,21)
1030  GOSUB 5000
1040 A(I,22) = PS
1050 A(I,23) = .6667 * A(I,22)
1060 A(I,24) = A(I,23) / ((.28 * A(I,21) / (A(I,6) + .34 * A(I,21))) + .5)
1070  GOTO 960
1080 L$ =  CHR$ (4): PRINT L$;"PR#1": FOR L = 1 TO N
1081 K = K - 12
1088  PRINT "%%%%%%%%%%%%%%%%%%%%%%"
1089  PRINT "%%%%%%%%%%%%%%%%%%%%%%"
1090  PRINT "OUTPUT FOR DIAMETER #"K" ,RUN #"I"."
1091  PRINT "%%%%%%%%%%%%%%%%%%%%%%"
1092  PRINT
1093  PRINT
1100 K = K + 12
1110  PRINT "DIAMETER ="A(I,K)" FEET   ","DEPTH ="A(I,21)" FEET"
1111  PRINT
1120  PRINT "S ="A(I,22)" PSF   ","S1 ="A(I,23)" PSF"
1121  PRINT
1130  PRINT "S2 ="A(I,24)" PSF","S2 ALLOW ="A(I,25)" PSF"
1131  PRINT
1140  PRINT "SL ="A(I,26)" PSF","SL ALLOW ="A(I,27)" PSF (ULTIMATE)"
1141  PRINT
1142  PRINT
1150  NEXT K
1158  PRINT "***********************"
1159  PRINT "***********************"
1160  PRINT "INPUT FOR RUN #"I"."
1161  PRINT "***********************"
1162  PRINT
```

```
1170  PRINT "ANGLE OF INTERNAL FRICTION ="A(I,1)" DEGREES"
1171  PRINT
1180  PRINT "COHESION ="A(I,2)" PSF"
1181  PRINT
1190  PRINT "KP ="A(I,28)
1191  PRINT
1200' PRINT "WET WEIGHT OF SOIL ="A(I,3)" PCF"
1201  PRINT
1210  PRINT "SATURATED WEIGHT OF SOIL ="A(I,4)" PCF"
1211  PRINT
1220  PRINT "WIND PRESSURE ="A(I,5)" PSF"
1221  PRINT
1230  PRINT "HEIGHT OF SIGN CENTROID ="A(I,6)" FEET"
1231  PRINT
1240  PRINT "AREA OF SIGN ="A(I,7)" SF"
1241  PRINT
1250  PRINT "LOAD ON POST ="A(I,8)" #"
1251  PRINT
1260  PRINT "HEIGHT OF POST LOAD ="A(I,9)" FEET"
1261  PRINT
1270  PRINT "DEPTH OF GWT ="A(I,10)" FEET"
1271  PRINT
1280  PRINT "SAFETY FACTOR ="A(I,12)
1281  PRINT
1284  PRINT "TOLERANCE =+/-"TL" FEET"
1285  PRINT L$;"PR#0"
1286  PRINT
1287  PRINT
1290  NEXT I
1300  END
5000  IF Z > A(I,10) GOTO 5030
5010 PS = ((A(I,3) * Z * A(I,28)) + (2 * A(I,2) * A(I,28) ^ .5)) / A(I,12)

5020  RETURN
5030 PS = ((A(I,3) * A(I,10) * A(I,28)) + (2 * A(I,2) * A(I,28) ^ .5) + ((
     A(I,4) - 62.4) * (Z - A(I,10)) * A(I,28))) / A(I,12)
5040  RETURN
6000 D = 1.18 * ((A(I,5) * A(I,7)) + A(I,8)) / A(I,K) / A(I,23) + ((1.18 *
     ((A(I,5) * A(I,7)) + A(I,8)) / A(I,K) / A(I,23)) ^ 2 + (A(I,5) * A(I,
     7) * A(I,6) + A(I,8) * A(I,9)) * 2.63 / A(I,K) / A(I,23)) ^ .5
6010  RETURN
```

2.6 Variable List (SIGNPOST 1)

Input

N	=	# of runs
A(I,1)	=	Phi angle
A(I,2)	=	Cohesion
A(I,3)	=	Wet soil weight
A(I,4)	=	Saturated soil weight
A(I,5)	=	Wind pressure
A(I,6)	=	Height of sign centroid
A(I,7)	=	Sign area
A(I,8)	=	Post load
A(I,9)	=	Load height
A(I,10)	=	GWT depth
A(I,11)	=	# of diameters
A(I,12)	=	Safety factor
A(I,J)	=	Diameter
A(I,28)	=	Passive earth pressure coefficient
TL	=	Tolerance

Flow Control

X = Question input

Counters

I = Run #

J = Diameter #

K = Output

Miscellaneous

Z	=	Depth
PS	=	Earth Pressure
A(I,22)	=	S
A(I,23)	=	S1
A(I,24)	=	S2
A(I,25)	=	S2 allowable
A(I,26)	=	SL
A(I,27)	=	SL allowable (ultimate)

2.7 Program Verification

```
          ++++++++++
          *SIGNPOST*
          ++++++++++


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DEPARTMENT OF GEOTECHNICAL ENGINEERING
DR. RICHARD D. BARKSDALE, ADVISOR


SYSTEM HARDWARE: APPLE II PLUS (64K)
SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE
PROGRAM DATE: APRIL, 1983


SIGNPOST ESTIMATES THE MINIMUM EMBEDMENT DEPTH OF A SINGLE CANTILEVERED POST FOU
NDATION.  THE CLASSICAL APPLICATION IS A SIGN OR MARQUE SUBJECTED TO WIND LOADS.


HOW MANY PROBLEM SETS DO YOU WANT TO RUN?  THE USER MAY INPUT SEVERAL POST DIAME
TERS PER PROBLEM SET.
?1


WHAT IS THE ANGLE OF INTERNAL FRICTION OF THE SOIL FOR RUN #1? (DEGREES)
?28
WHAT IS THE COHESION OF THE SOIL FOR RUN #1? (PSF)
?200
WHAT IS THE WET WEIGHT OF THE SOIL FOR RUN #1? (PCF)
?110
WHAT IS THE SATURATED WEIGHT OF THE SOIL FOR RUN #1? (PCF)
?122.4
WHAT IS THE WIND PRESSURE AGAINST THE SIGN FOR RUN #1? (PSF)
?40
WHAT IS THE HEIGHT ABOVE GRADE TO THE CENTROID OF THE SIGN FOR RUN #1? (FEET)
?107.5
WHAT IS THE AREA OF THE SIGN FOR RUN #1? (SF)
?450
WHAT IS THE LOAD ON THE POST FOR RUN #1? (POUNDS)
?1000
WHAT IS THE HEIGHT ABOVE GRADE OF THE POST LOAD FOR RUN #1? (FEET)
?50
WHAT IS THE DEPTH BELOW GRADE OF THE GROUND WATER TABLE FOR RUN #1? (FEET)
?15
```
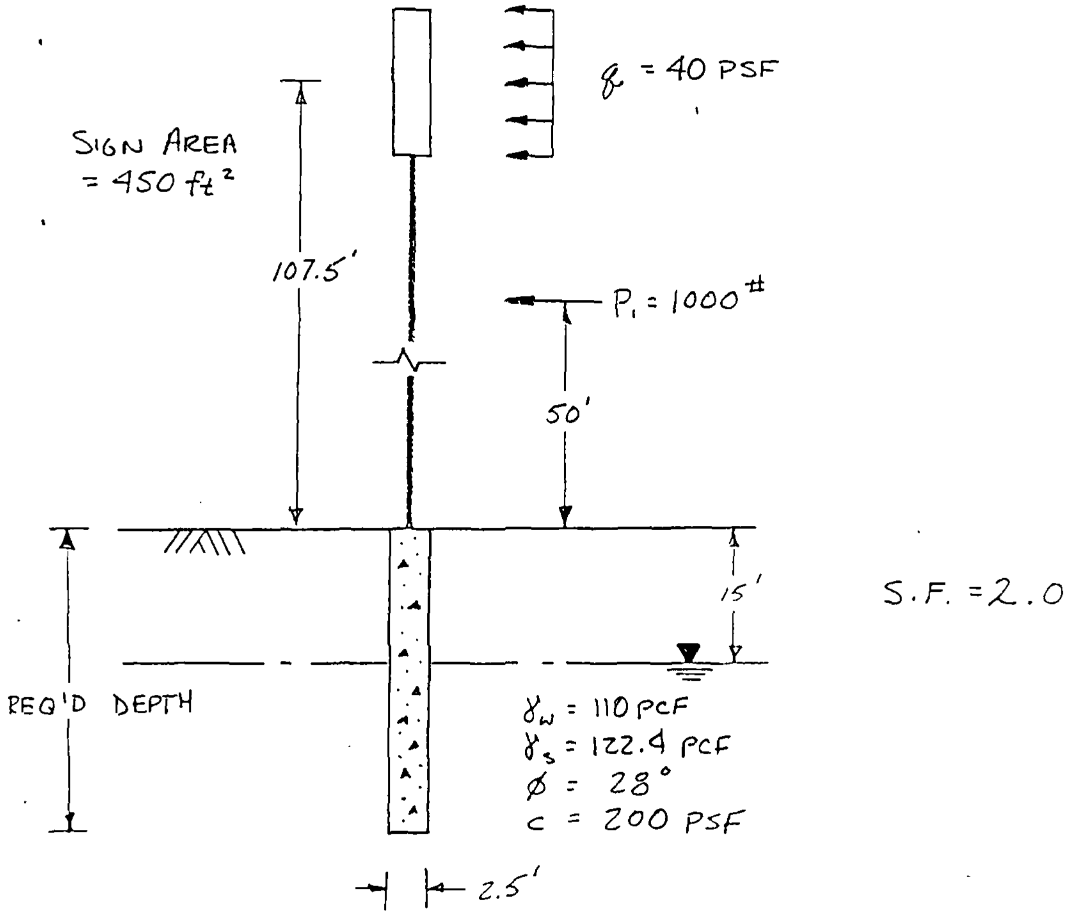

```
HOW MANY POST HOLE DIAMETERS DO YOU WANT TO INPUT FOR RUN #1?
?3
WHAT IS DIAMETER #1 (FEET)
?2.0
WHAT IS DIAMETER #2 (FEET)
?2.5
WHAT IS DIAMETER #3 (FEET)
?3.0
WHAT IS THE SAFETY FACTOR FOR RUN #1?
?2
INPUT THE TOLERANCE FOR DEPTH CALCULATION. (RECOMMEND  .5 - 1.0 FT)
?.5
DO YOU WANT TO INPUT THE COEFFICIENT OF PASSIVE EARTH PRESSURE (KP) ,(YES), OR H
AVE SIGNPOST CALCULATE KP FOR YOU (NO) ?
?NO
%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%
OUTPUT FOR DIAMETER #1 ,RUN #1.
%%%%%%%%%%%%%%%%%%%%%%%


DIAMETER =2 FEET                   DEPTH =45.5 FEET

S =2654.82639 PSF                  S1 =1769.97275 PSF

S2 =2932.34826 PSF                 S2 ALLOW =3939.17206 PSF

SL =5864.69651 PSF                 SL ALLOW =10295.936 PSF (ULTIMATE)


%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%
OUTPUT FOR DIAMETER #2 ,RUN #1.
%%%%%%%%%%%%%%%%%%%%%%%


DIAMETER =2.5 FEET                 DEPTH =41.5 FEET

S =2480.34245 PSF                  S1 =1653.64431 PSF

S2 =2776.66116 PSF                 S2 ALLOW =3713.35364 PSF

SL =5553.32233 PSF                 SL ALLOW =9631.76239 PSF (ULTIMATE)
```

```
%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%
OUTPUT FOR DIAMETER #3 ,RUN #1.
%%%%%%%%%%%%%%%%%%%%%%

DIAMETER =3 FEET                 DEPTH =38.5 FEET

S =2325.09187 PSF                S1 =1550.13875 PSF

S2 =2630.05603 PSF               S2 ALLOW =3543.98878 PSF

SL =5260.11206 PSF               SL ALLOW =9133.6322 PSF (ULTIMATE

**********************
**********************
INPUT FOR RUN #1.
**********************

ANGLE OF INTERNAL FRICTION =28 DEGREES

COHESION =200 PSF

KP =2.76738895

WET WEIGHT OF SOIL =110 PCF

SATURATED WEIGHT OF SOIL =122.4 PCF

WIND PRESSURE =40 PSF

HEIGHT OF SIGN CENTROID =107.5 FEET

AREA OF SIGN =450 SF

LOAD ON POST =1000 #

HEIGHT OF POST LOAD =50 FEET

DEPTH OF GWT =15 FEET

SAFETY FACTOR =2

TOLERANCE =+/-.5 FEET
```



$$k_p = \tan^2(45 + \phi/2) = \tan^2(45 + 28/2)$$

$$= \underline{\underline{2.77}}$$

<u>FOR $z \leq 15'$</u>

$$p_p = \left(\gamma_w (z)\, k_p + 2c\sqrt{k_p}\right) / SF$$

<u>FOR $z \geq 15'$</u>

$$p_p = \left[\gamma'_w (GWT) + (\gamma_s - \gamma_{H_2O})\,(z - GWT)\right) k_p + 2c\sqrt{k_p}\Big] / SF$$

ASSUME $D = 41.5'$

CALCULATE S @ $Z = .34D = .34(41.5') = 14.11'$

$$S = P_p = \left(110(14.11')\,2.77 + 2(200)\sqrt{2.77}\right)/2$$

$$= 2482.5\ \#/Ft^2$$

CALCULATE S1

$$S1 = \tfrac{2}{3}S = \tfrac{2}{3}(2482.5)$$

$$= 1655.0\ \#/Ft^2$$

CALCULATE D

$$D = \frac{1.18(P+P_1)}{b\ S1} + \sqrt{\left(\frac{1.18(P+P_1)}{b\ S1}\right)^2 + \frac{((P \cdot H)+(P_1 \cdot H_1)) \cdot 2.63}{b\ S1}}$$

$$P = 450\,Ft^2 \cdot 40\,\#/Ft^2 = 18{,}000.0\ \#$$

$$D = \frac{1.18(1000+18{,}000)}{(2.5)\,1655} + \sqrt{\left(\frac{1.18(1000+18000)}{(2.5)\,1655}\right)^2 + \frac{((18000 \cdot 107.5)+(1000 \cdot 50)) \cdot 2.63}{(2.5)\,1655}}$$

$$= 5.419 + \sqrt{29.363 + 1261.76}$$

$$= \underline{\underline{41.35' \approx 41.5'}} \qquad OK$$

CHECK S2 & SL

$$S1/S2 = \frac{.28D}{H + .34D} + 1/2$$

$$= \frac{.28(41.35')}{107.5 + .34(41.35)} + 1/2$$

$$= .595$$

$$S2 = S1/.595$$

$$= 1655/.595$$

$$= \underline{2780.4\ \#/Ft^2}$$

$$S2_{ALLOW} = P_p \text{ @ } Z = .68D = 28.12'$$

$$S2_{ALLOW} = [(110(15) + (122.4 - 62.4)(28.12 - 15))\,2.77 + 2(2\ldots)\sqrt{2.77}\,]/2$$

$$= \underline{3708.4}\ \#/Ft^2$$

$$\underline{S2 < S2_{ALLOW}}$$

$$SL = 2(S2) = 2(2780.4)$$

$$= \underline{5560.8\ \#/Ft^2}$$

$$SL_{ALLOW} = P_p \text{ (ULTIMATE, SF=1) @ } Z = D = 41.35'$$

$$SL_{ALLOW} = (110(15) + (122.4 - \ldots 2.4)(41.35 - 15))\,2.77 + 2(200)\sqrt{2.77}$$

$$= \underline{9615.6}\ \#/Ft^2$$

$$\underline{SL < SL_{ALLOW}}$$

$$\underline{\underline{\text{REQUIRED DEPTH} = 41.35'}}$$

2.8 References

1. Seiler, J. F., "Effect of Depth of Embedment on Pole Stability," Wood Preserving News, Vol. 10, No. 11, Nov. 1932.

2. Patterson, Donald, How to Design Pole-Type Buildings, American Wood Preservers Institute, 1957.

3. Ivey, D. L. and Hawkins, L., "Signboard Footings to Resist Wind Loads," Civil Engineering, ASCE, Dec. 1966.

Recommended Reading

1. Foundation Depths for Self-Supporting Poles Subjected to Transverse Loads, Lieut. Comdr. James R. Griffith, U. S. Navy, 1939.

2. A Report of Field and Laboratory Tests on the Stability of Posts Against Lateral Loads, W. L. Shilts, L. D. Graves, G. G. Driscoll, Notre Dame University, 1948.

3. Engineering Design Manual, Outdoor Advertising Association of America, 1955.

4. Saghera, S. S., "Embedment Depth for Nonconstrained and Constrained Poles or Posts," Civil Engineering, ASCE, May 1973.

CHAPTER III

CANTILEVERED WALL

3.1 Problem Definition

CANTWALL 1 calculates the required embedment depth of a cantilevered wall. Although cantilevered wall heights are limited by structural constraints due to high bending moments in the wall, CANTWALL 1 can calculate the theoretical penetration depth required to support any height of wall. The limitations of wall height are discussed in more detail in Section 3.4. As depicted in Figure 3.1, the vertical wall penetrates through two soils. The soil characteristics are specified in terms of angle of internal friction, cohesion, saturated, and wet unit weight. A friction angle for the soil-wall interface must also be specified. The ground water table can be specified to exist anywhere from the top of Soil #1 to any depth below grade.

CANTWALL 1 satisfies the static summation of horizontal forces and moments.

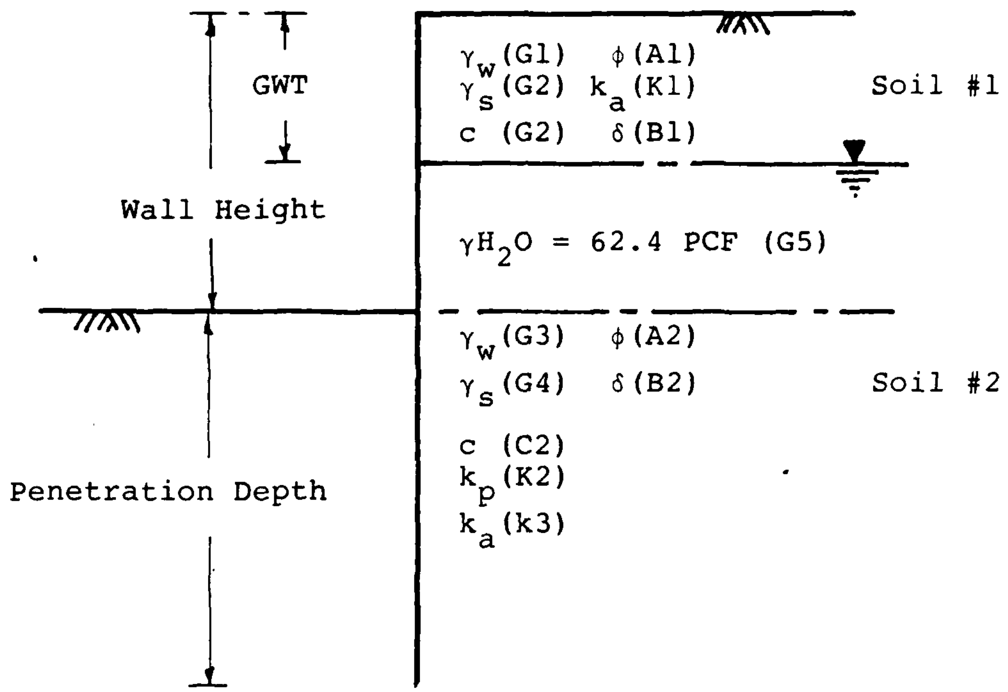


Figure 3.1. General Problem Diagram Cantilevered Wall.

3.2 Background Theory

3.2.1 General Definition

A cantilevered sheetpile wall depends upon its embedment depth to develop resistance against the overturning effect of a soil backfill. Cantilevered walls develop their strength through passive pressure in the lower soil thus counteracting the active earth pressure in the backfill. These walls do not depend upon an anchor in the backfill for support.

As depicted in Figure 3.2(A), cantilevered walls rotate about a point in the lower soil [1].

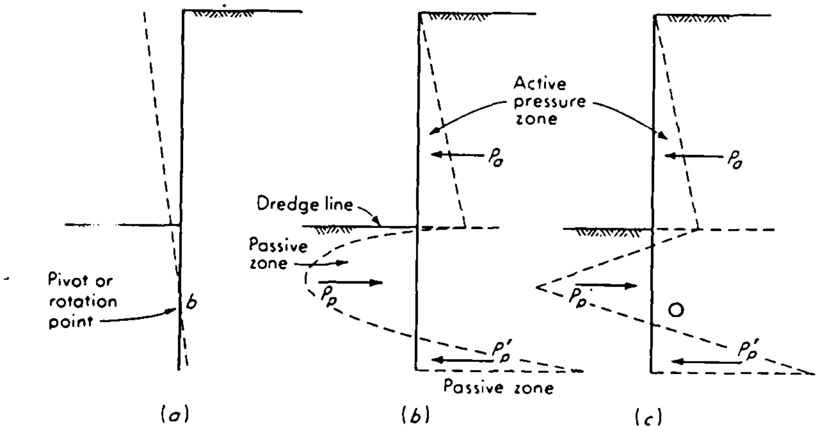


Figure 3.2 (*a*) Assumed elastic line of the sheetpiling; (*b*) probable and as obtained in finite-element solution qualitative soil-pressure distribution; (*c*) simplified pressure diagram for computational purposes (granular soil and no water as shown). [1]

Through model testing and field experience, the earth pressures mobilized as the wall rotates are shown in Figure 3.2 (b) [1]. For ease of calculation, these pressures have been simplified, Figure 3.2 (c).

The classic solution of the cantilevered wall involves assuming a trial embedment depth and varying the passive pressures in the lower soil until the summation of horizontal forces approximate zero. Moments are summed about the point of zero shear (Point o, Figure 3.2 (c)) in the lower soil. If the net moment indicates the wall will overturn, a deeper depth is assumed until a safe condition is calculated.

Two methods for applying a safety factor have been used. The passive pressures in the lower soil can be reduced by a factor, or the calculated depth increased by 20% to 40% [2].

Although there are other methods, the Rankine theory of earth pressure is used to calculate the coefficients of earth pressure.

$$k_a = \frac{\sin^2(\alpha+\phi)}{\sin^2\alpha \ \sin(\alpha-\delta) \left[1 + \sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\delta)\sin(\alpha+\beta)}}\right]^2}$$

$$k_p = \frac{\sin^2(\ -\ )}{\sin^2\alpha \ \sin(\alpha+\delta) \left[1 - \sqrt{\dfrac{\sin(\phi+\delta)\sin(\phi+\beta)}{\sin(\alpha+\delta)\sin(\alpha+\beta)}}\right]^2}$$

where,

α = wall inclination from horizontal

β = backfill inclination from horizontal

δ = wall-soil friction angle

ϕ = angle of internal friction

Similarly, the Rankine equations for plastic soil behavior are used to calculate the active and passive states [3].

$$\sigma_a = \gamma Z k_a - 2c\sqrt{k_a}$$

$$\sigma_p = \gamma Z k_p + 2c\sqrt{k_p}$$

where,

σ_a = active earth pressure

σ_p = passive earth pressure

γ = unit soil weight

Z = soil depth

C = cohesion

Effective stresses are considered using bouyant soil weights in the above equations. Water pressure is superimposed on the earth pressures when the soil is saturated.

In cohesive soils, tension cracks will develop when the soil is allowed to expand. This is the case in active pressure zones. The backfill, or soil #1 as referred to in this text, is an active zone. The depth of these tension cracks are calculated as [3]:

$$Z_o = \frac{2c}{\gamma}\sqrt{k_p}$$

where,

Z_o = tension crack depth

γ = soil unit weight

c = cohesion

k_p = passive coefficient

Any water that may accumulate in the tension cracks is considered in the computation of the active force in the backfill. Figure 3.3(A) illustrates the active pressures mobilized behind the wall for cohesive soils. The cohesive

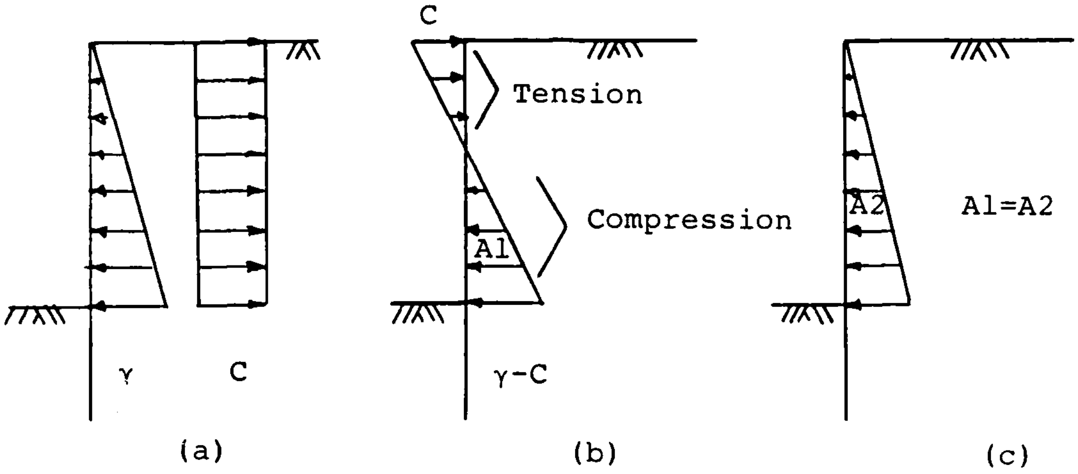


Figure 3.3. Equivalent Active Pressure.
(a) Separate Ranking Pressure Distribution
(b) Combined Pressure Diagram
(c) Equivalent Active Force

component of the soil tends to counteract the active force mobilized by the soil weight. In certain cases when the backfill has a high cohesion (C = 1000 - 2000 PSF), the net active pressure is equal to or less than zero; consequently, the soil can theoretically stand unsupported. This premise is time dependent as changes in water content and time can alter the available cohesion in soil.

3.2.2 Equivalent Active Force

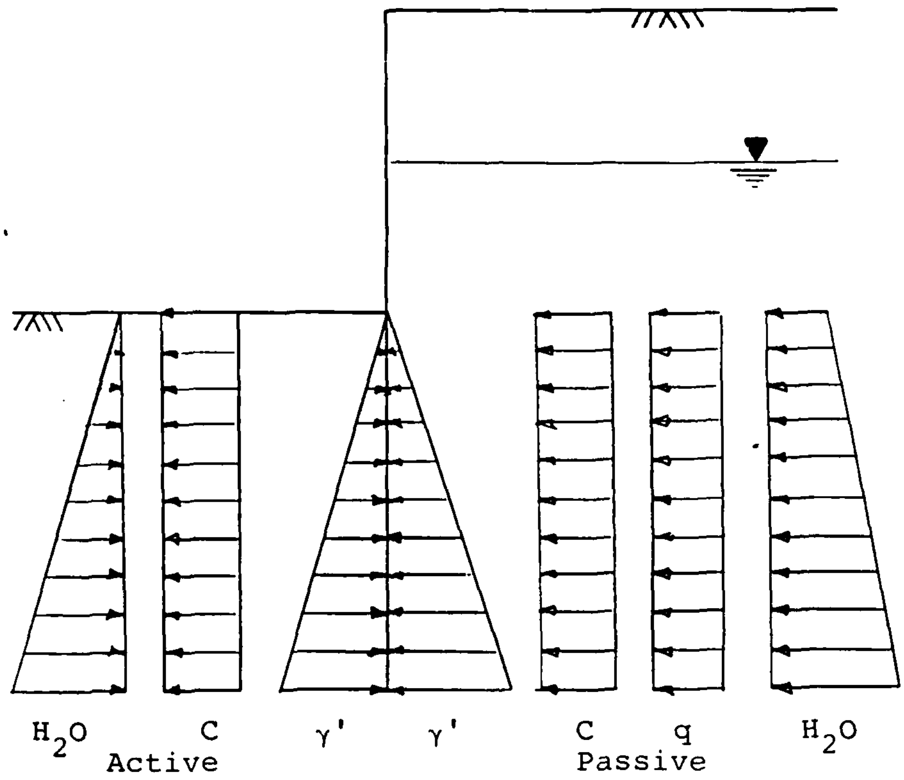
In cases where a net positive active force exists in the cohesive backfill, an equivalent active force may be used. Figure 3.3 (b) illustrates this condition. For computation the positive active force (A1) is used. The negative cohesive active force is ignored. Force A1

is distributed along the entire height of the wall (A2). Figure 3.3 (c) illustrates the final pressure distribution of the equivalent active force concept. In addition to disregarding the negative cohesive force and its contribution to moment, the equivalent active force method increases the lever arm distance thus increasing the overturning moment and ultimately the required penetration.

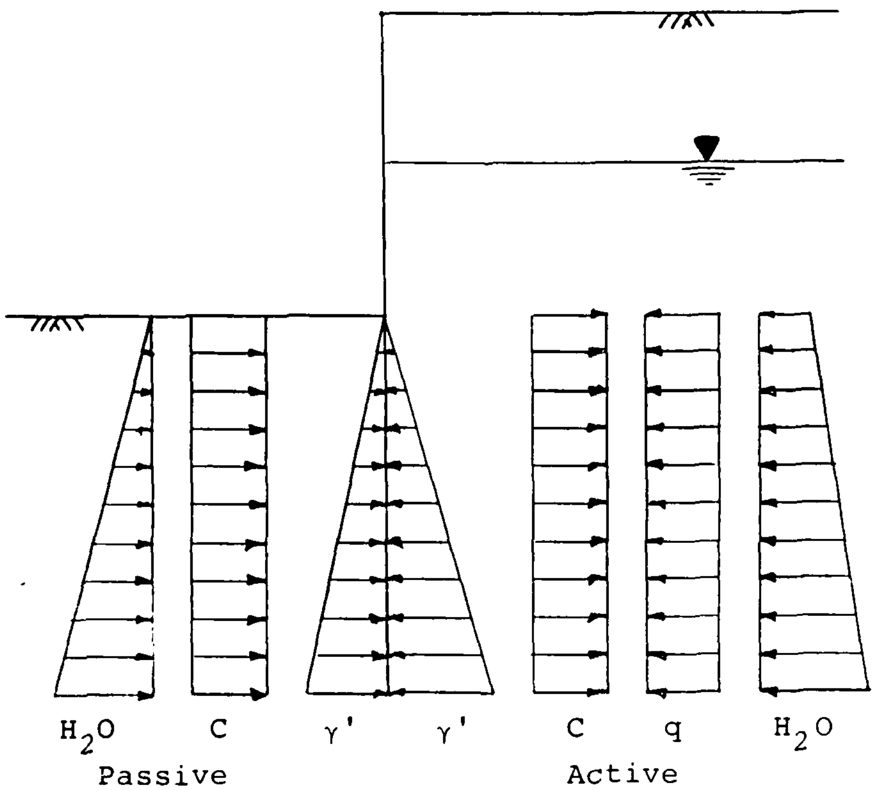
3.2.3 Pressure Calculation, Soil #2

To complete the soil pressure in the lower soil (Soil #2), active and passive pressures are calculated for each side of the embedded wall. Figure 3.4 illustrates the various components of the earth pressures. As previously mentioned, a factor of safety can be applied by reducing the passive pressures. The active pressure of one side is subtracted from the passive pressure of the other side. The resulting combined pressure diagrams are shown in Figure 3.5. In general, a granular, noncohesive soil will have a pressure diagram similar to Figure 3.5 (b); conversely, a cohesive soil will have a combined pressure diagram similar to Figure 3.5 (a). P2 represents the pressure at the soil interface and will be discussed in more detail in Section 3.4.

The pressure against the embedded depth of wall is varied by altering Line L1 which is drawn from the lower right hand side pressure diagram up to an arbitrary point on the left hand side pressure diagram. The actual pressure

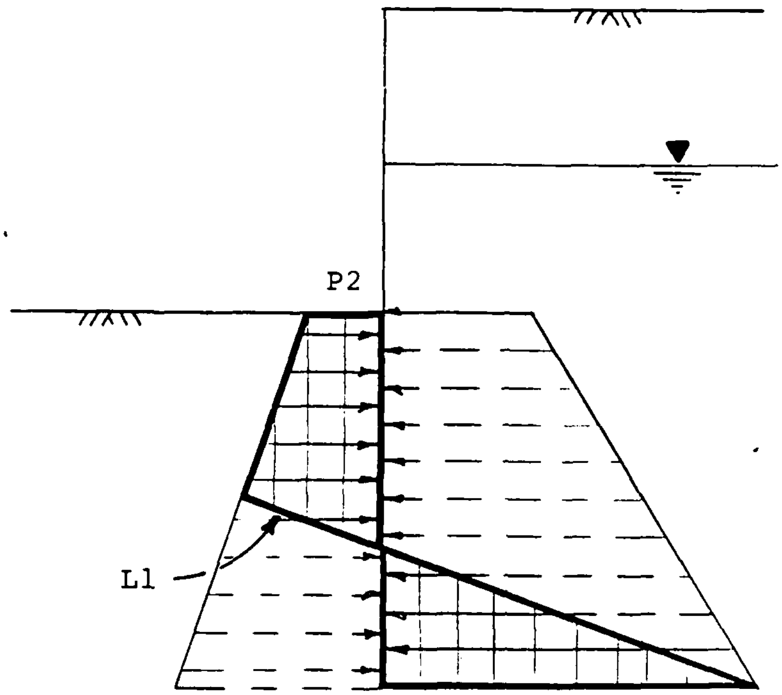


(a) Right Side Pressure Considerations.

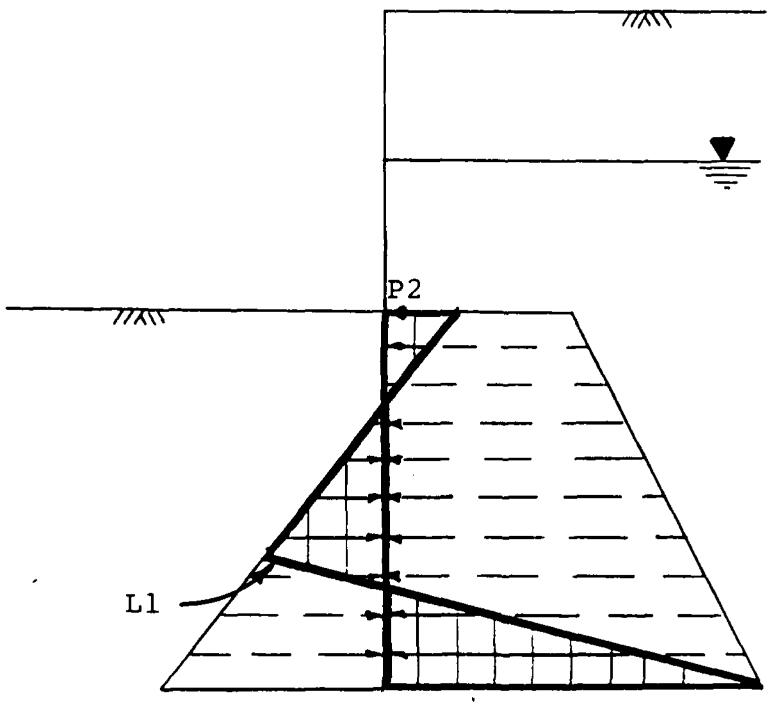


(b) Left Side Pressure Considerations.

Figure 3.4. Earth Pressures in Soil #2.



(a) Combined Pressure Diagram (-P2)



(b) Combined Pressure Diagram (+P2)

Figure 3.5. Combined Earth Pressures.

distribution is approximated as in Figure 3.2. Line L1 is varied until the summation of horizontal forces approaches zero. Although the active forces in soil #1 is emitted from the diagram, the forces are considered in the summation of forces and moments. Moments are summed about the point where the line crosses the embedded wall. The net moment indicates whether the assumed depth needs to be increased or decreased. The entire sequence is repeated for a new depth until static equilibrium is achieved.

3.3 Programming Rationale

3.3.1 Program Flow

The program flow is executed similar to a manual calculation. As depicted in Figure 3.6, the problem necessitated four main branches. Each branch is contingent upon the location of the ground water table. If the water table is in soil #1, the program will iterate within one branch exclusively. This is typically true if the water table is specified to be deeper than the originally assumed wall penetration and the calculated wall penetration. The program must iterate between branches when the water table is within the embedded wall depth.

As previously defined, the pressures in soil #2 are varied until static equilibrium is achieved. The pressures in soil #1 do not change during iterations; therefore, the program minimizes the number of times the pressures are calculated. To vary soil #2 pressures, the depth to

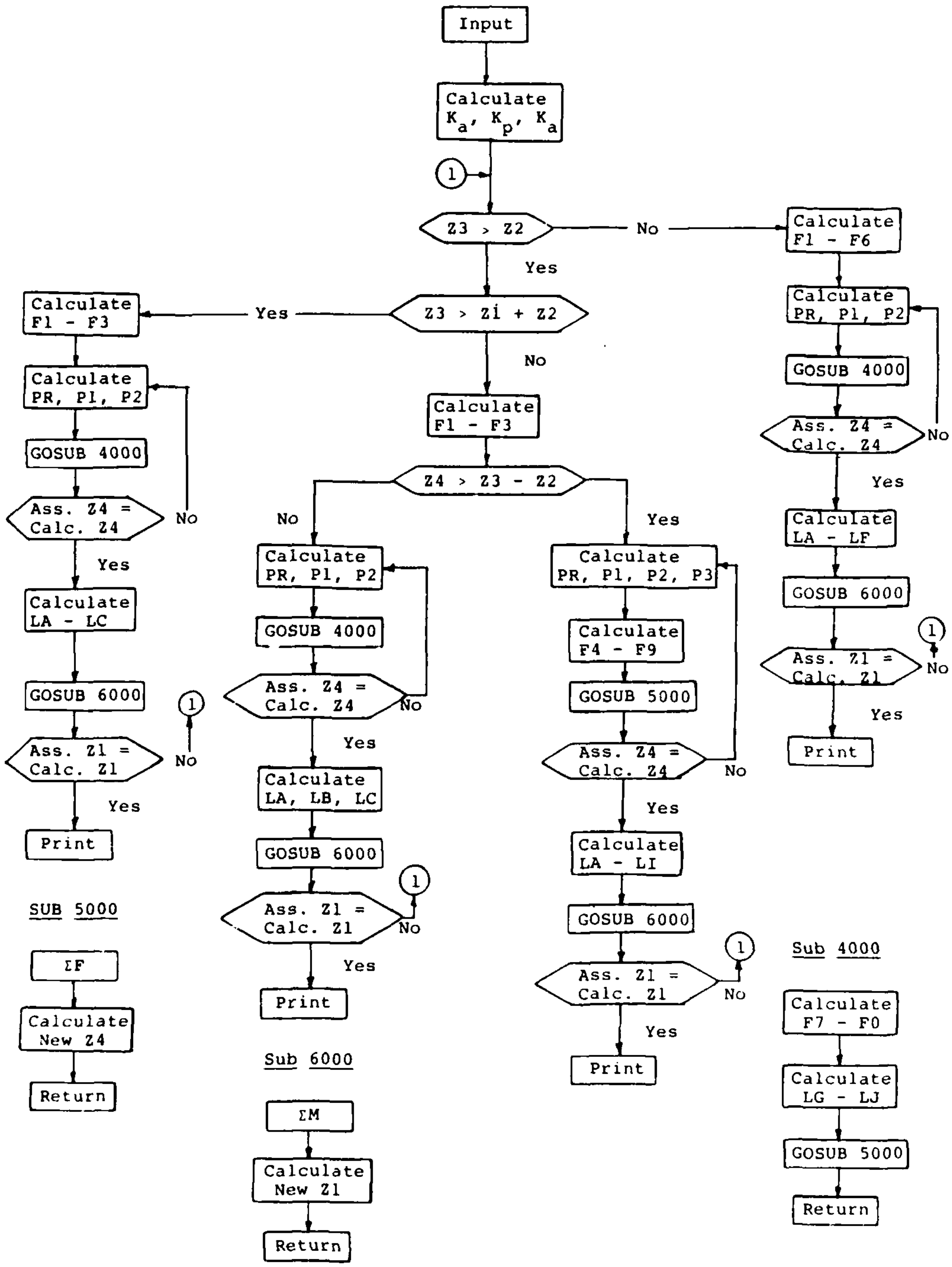


Figure 3.6. CANTWALL Flow Chart.

the maximum pressure on the left hand side of the combined pressure diagram is increased or decreased depending upon the previously calculated net horizontal force. If the net sum of horizontal forces is positive (to the left), the depth of maximum left side pressure is increased thus increasing the negative pressure (left side pressure to the right). As described in Section 3.4, the depth to the maximum pressure is defined as Z4.

3.3.2 Iteration by Slope-Intercept

To reduce the number of iterations required to balance horizontal forces, a slope intercept method was employed which would increase or decrease Z4 toward a projected new Z4 which corresponds to a net summation of horizontal forces of zero. Figure 3.7 illustrates this slope-intercept concept.

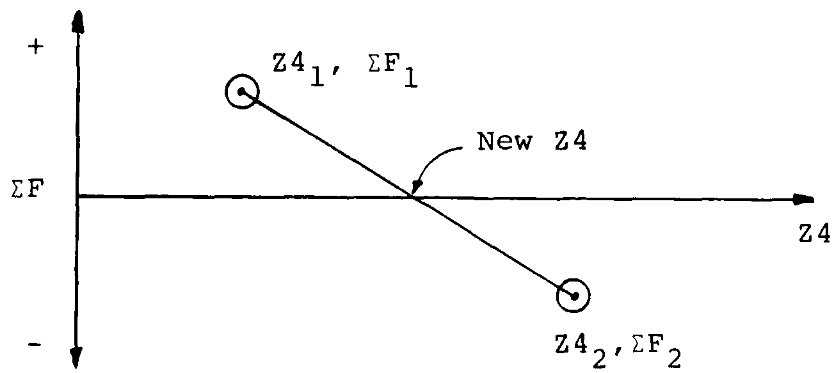


Figure 3.7. Slope-Intercept Search Method.

After using the above routine, it was found that only three iterations were required to balance the horizontal forces of the system. This indicates a linear relationship between the summation of horizontal forces and Z4. The same method is used for establishing the best new embedment depth (Z1) compared against the summation of moments. The program iterates up to 15 times prior to balancing the moments; thus, Z1 is not linearly related to the summation of moments.

3.3.3 Sign Convention

To simplify calculations, the sign convention was established such that all forces to the right are negative and forces to the left are positive. Counterclockwise moments are positive; therefore, all lever arms are positive except the lever arm associated with the lower right hand side force in soil #2. This lever arm is negative because the summation of moments is about point 0 (Figure 3.2c) and as previously mentioned, forces to the left are positive.

Subroutines are used as much as possible to reduce repetitious program lines. The calculation of pressures in soil #2, the summation of forces (5000), and the summation of moments (6000) are the main subroutines.

3.4 Program Use and Limitations

3.4.1 Input

CANTWALL 1 is a user-oriented program. All input and options are prompted by statements and questions which instruct the user that a particular input is necessary. As with all programs, the user should be familiar with the input variables prior to beginning the run. This will prevent inputting incorrect or mistaken variables. A sample of the prompting questions are presented in Section 3.7. The user must input the following variables (refer to Figure 3.1):

a) number of runs

b) wet weight, soil #1

c) saturated weight, soil #1

d) cohesion, soil #1

e) Phi angle, soil #1

f) wall-soil friction angle, soil #1 (see Table 3.1)

g) wet weight, soil #2

h) saturated weight, soil #2

i) cohesion, soil #2

j) Phi angle, soil #2

k) wall-soil friction angle, soil #2 (see Table 3.1)

l) wall height

m) ground water table depth

n) tolerance

o) safety factor

Table 3.1. Friction Angles for Various Interface Materials [2].

Interface Materials	Friction factor, tan δ	Friction angle, δ degrees
Mass concrete on the following foundation materials:		
Clean sound rock..................................	0.70	35
Clean gravel, gravel-sand mixtures, coarse sand...	0.55 to 0.60	29 to 31
Clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel....................	0.45 to 0.55	24 to 29
Clean fine sand, silty or clayey fine to medium sand..	0.35 to 0.45	19 to 24
Fine sandy silt, nonplastic silt..................	0.30 to 0.35	17 to 19
Very stiff and hard residual or preconsolidated clay..	0.40 to 0.50	22 to 26
Medium stiff and stiff clay and silty clay........	0.30 to 0.35	17 to 19
(Masonry on foundation materials has same friction factors.)		
Steel sheet piles against the following soils:		
Clean gravel, gravel-sand mixtures, well-graded rock fill with spalls..........................	0.40	22
Clean sand, silty sand-gravel mixture, single size hard rock fill..................................	0.30	17
Silty sand, gravel or sand mixed with silt or clay	0.25	14
Fine sandy silt, nonplastic silt..................	0.20	11
Formed concrete or concrete sheet piling against the following soils:		
Clean gravel, gravel-sand mixture, well-graded rock fill with spalls..........................	0.40 to 0.50	22 to 26
Clean sand, silty sand-gravel mixture, single size hard rock fill..................................	0.30 to 0.40	17 to 22
Silty sand, gravel or sand mixed with silt or clay	0.30	17
Fine sandy silt, nonplastic silt..................	0.25	14
Various structural materials:		
Masonry on masonry, igneous and metamorphic rocks:		
Dressed soft rock on dressed soft rock..........	0.70	35
Dressed hard rock on dressed soft rock..........	0.65	33
Dressed hard rock on dressed hard rock..........	0.55	29
Masonry on wood (cross grain)....................	0.50	26
Steel on steel at sheet pile interlocks...........	0.30	17

p) option, tension cracks in soil #1

q) option, equivalent active force in soil #1

r) option, input coefficient of earth pressure or calculate

s) assumed penetration depth

3.4.2 Units

All input is in the units of feet, pounds, and degrees. The units may be altered by changing line 744 (G5 = 62.4) which establishes the unit weight of water as 62.4 PCF. Angles must be input in degrees. Although the units of the input variables may be changed, the print statement will label all output in the original units.

3.4.3 Repeat Runs

Each run is totally independent of the previous run; all input will be required again. This function saves time by eliminating the introductory statements and the system commands the user must execute to run the program.

Input variables b)-l) are self explanatory and are depicted in Figure 3.1. The depth of the ground water table is taken from the surface of soil #1.

3.4.4 Tolerance

The tolerance for depth calculation is recommended as 0.1 to 0.01. The tolerance is used during the summation of forces and moments routines. The tolerance is the maximum difference between a calculated depth and the new assumed depth. For force summations, Z4 is compared and for moment summations, Z1 is used.

3.4.5 Safety Factor

CANTWALL uses the safety factor to decrease the passive pressures in soil #2 prior to creating a combined pressure diagram. This method was previously described in Section 3.2. When specifying a soft cohesive soil for soil #2, it is recommended to use a safety factor of 1 as the resulting combined pressure diagrams will indicate wall instability. This is discussed in more detail later in this section.

3.4.6 Options

The user may exercise three options; i.e., specify tension cracks in soil #1, specify an equivalent active force in soil #1, and input the coefficients of earth pressure versus using the values calculated by the program.

The theoretical depth of tension cracks as described in Section 3.2 are used when this option is exercised. With this option, the force due to water pressure in the crack is included. The force is calculated from hydrostatic pressure for the calculated tension crack depth. The problem checks the crack depth against the ground water table depth and the wall height. The crack depth can not exceed the wall height or the depth of the water table.

The equivalent active force option is calculated as described in Section 3.2 (Figure 3.3). Because the tensile effect of cohesion is ignored and the lever arm of the positive force is increased, the overall effect of exercising this option is to increase the required wall penetration.

The program allows the user to input the coefficients of earth pressure. If the user exercises this option, the program will not calculate the coefficients as defined in Section 3.2. The user will be required to input the active coefficient for soil #1 and the active and passive coefficient for soil #2. All input will be prompted by questions if the option is used.

3.4.7 Output

Printed output consists of a list of input variables and the required penetration depth. A supplementary data list is available giving the value of the variables used in the programs. After the required penetration depth is printed, the user is prompted by a question asking if the list of variables is desired. Figures 3.8 to 3.13 serve as a guide for interpreting the supplementary variables listing.

To locate the proper diagram, the user must know the ground water table depth (Z3), the wall height (Z2), and from the supplementary list, know the values of Z1, Z4, and P2. If Z4 is less than Z2, Figures 3.8 or 3.9 apply; if P2 is positive, Figure 3.9 applies. Table 3.2 is provided to easily identify the proper figure.

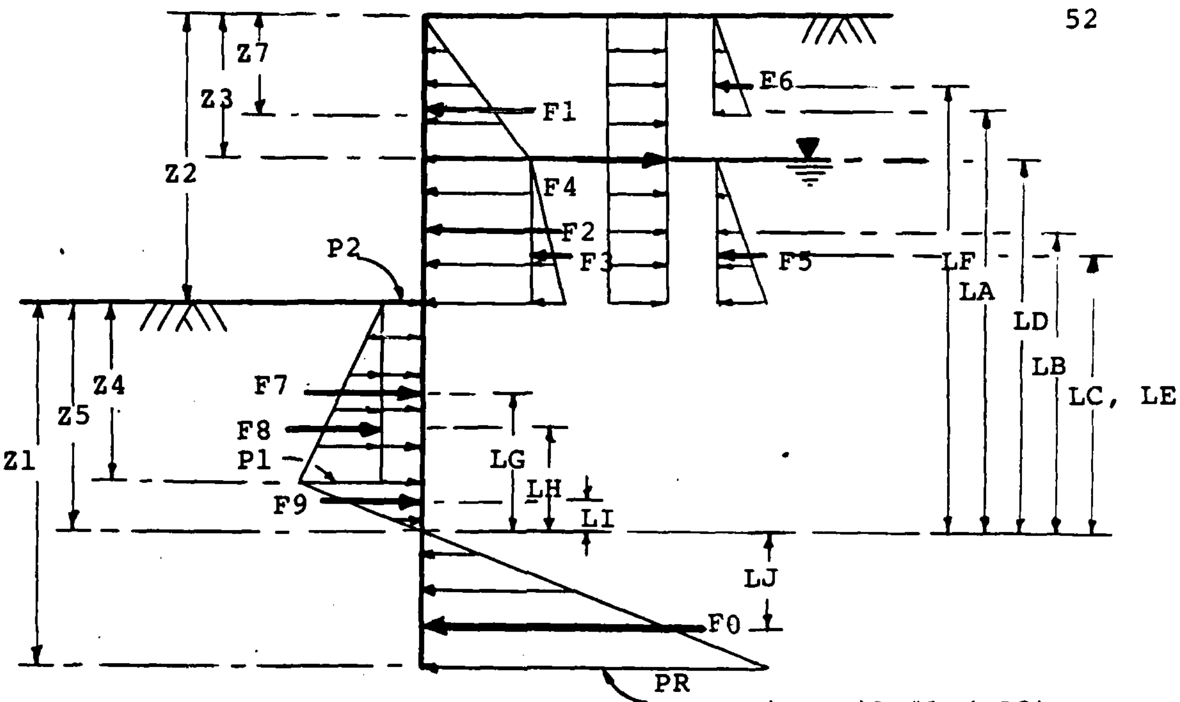


Figure 3.8. Forces and Lever Arms, GWT in Soil #1 (-P2).

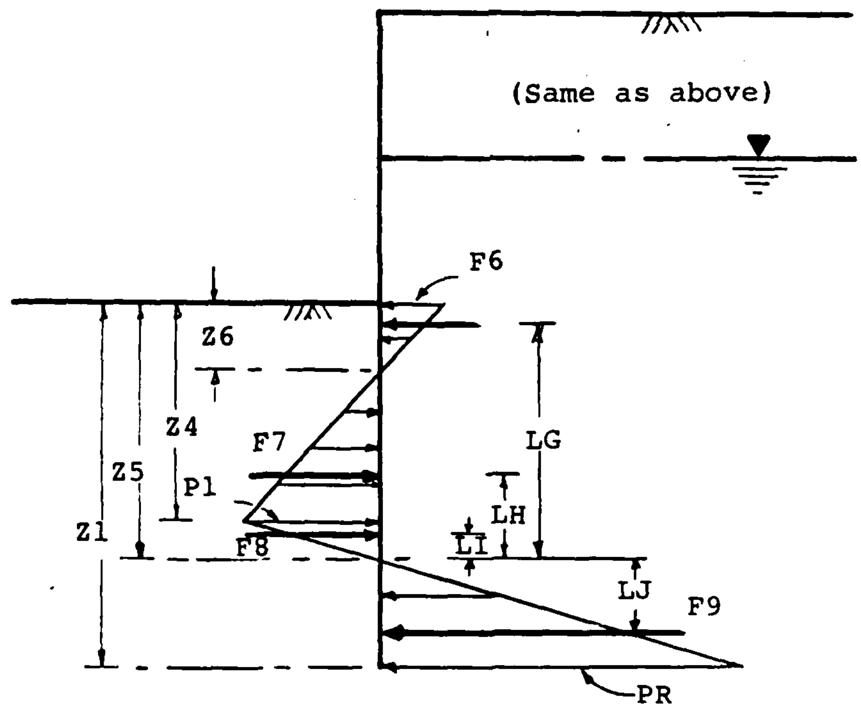


Figure 3.9. Forces and Lever Arms, GWT in Soil #1 (+P2).

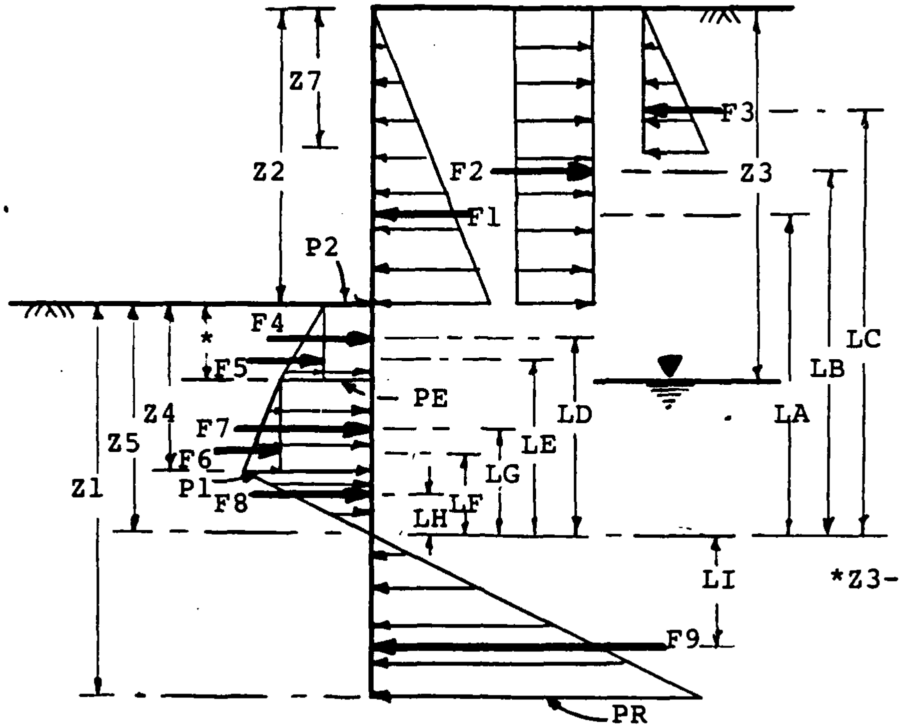


Figure 3.10. Forces and Lever Arms, GWT in Soil #2 (-P2) (Z3 < Z4 + Z2).

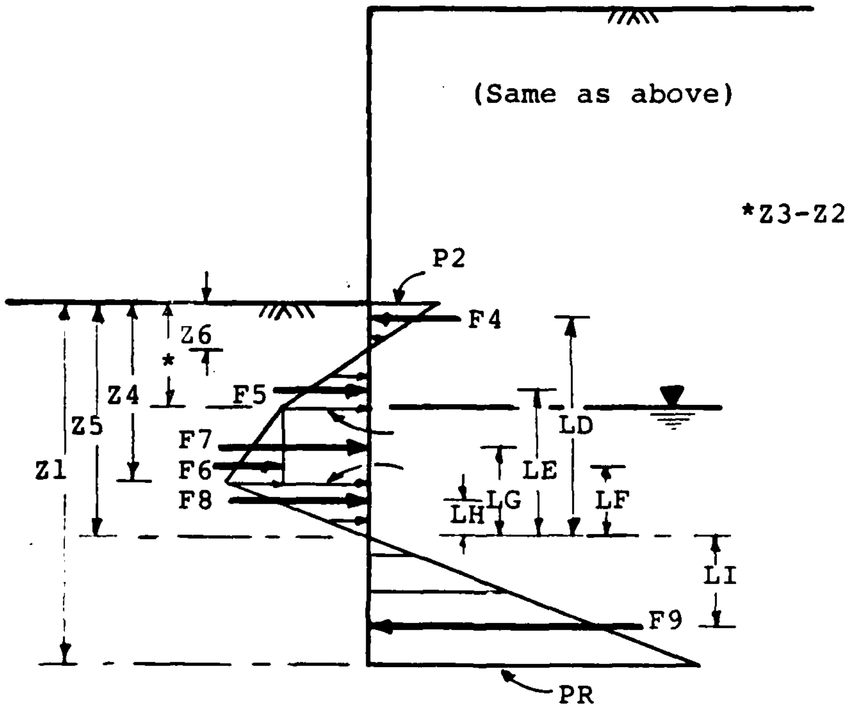


Figure 3.11. Forces and Lever Arms, GWT in Soil #2 (+P2) (Z3 < Z4 + Z2).

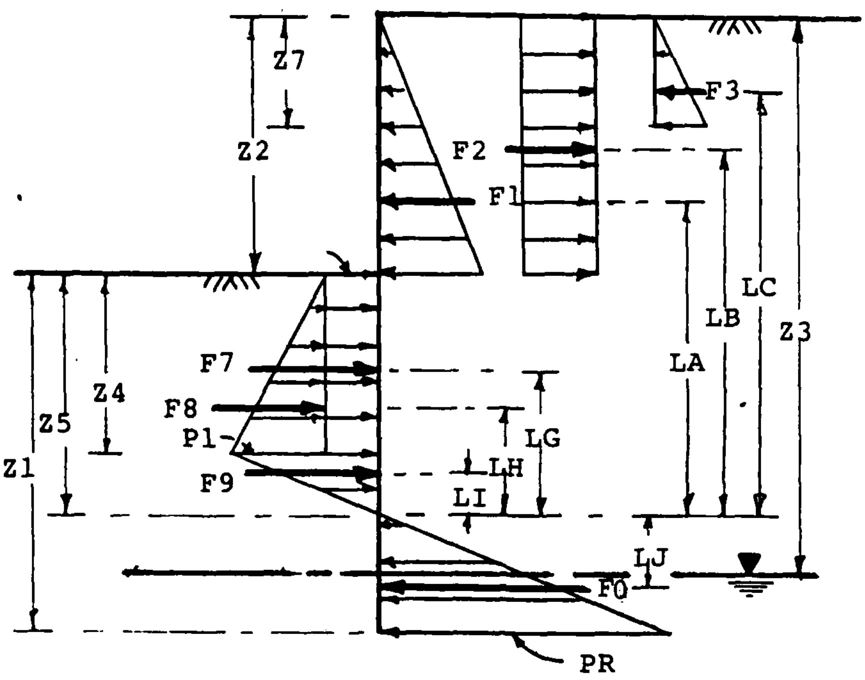


Figure 3.12. Forces and Lever Arms, GWT in Soil #2 (-P2) (Z3 > Z4 + Z2).

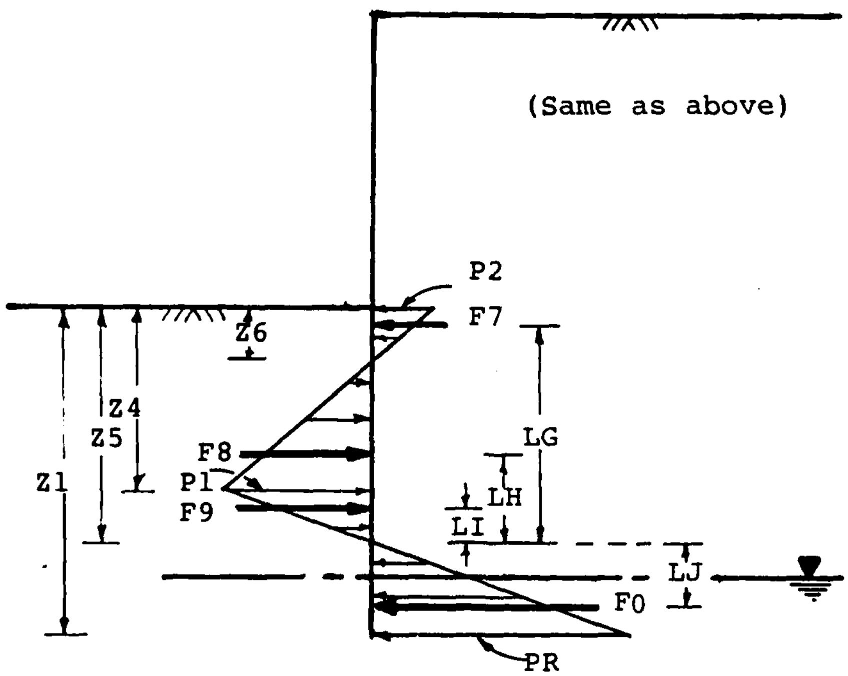


Figure 3.13. Forces and Lever Arms, GWT in Soil #2 (+P2) (Z3 > Z4 + Z2).

Table 3.2. Figure Identification.

GWT Depth	Figure +P2	Figure -P2
Z3 < Z2	3.9	3.8
Z2 < Z3 < Z4 + Z2	3.11	3.10
Z4 + Z2 < Z3 < Z1	3.13	3.12
Z3 > Z1 (soil #2)	3.9	3.8
Z3 > Z1 (soil #1)	3.11	3.10

A separate figure is not included for Z3 > Z1 because the correlation of data to the figures is identical to those already shown. When Z3 > Z1 use the forces and lever arms of Figures 3.8 and 3.9 for soil #2; similarly, use Figures 3.10 and 3.11 for soil #1. Forces and lever arms consistently correspond to each other; i.e., LA is always the lever arm for F1, LE is the lever arm for F5, and LJ is the lever arm for F0.

CANTWALL will many times calculate a lever arm that is not used but will be printed in the supplementary list. As long as the corresponding force is zero, the user can summize that the particular force and lever arm was not a part of the calculation.

In the first problem in Section 3.7, the supplementary data list indicates FG = 0# and LF = 24.23 ft. Referring to Figure 3.8, the user finds that F6 is the water pressure

due to tension cracks and that since FG = 0#, tension cracks were not specified and that although LF was calculated, it did not affect the summation of forces or moments.

3.4.8 Error Warning

CANTWALL uses warnings to prevent the user from specifying problem parameters that can yield incorrect solutions. The warning, "Assumed depth must be increased" followed by the prompting statement, "Input assumed depth" will be printed on the monitor when Z4 exceeds Z1. Referring to Figure 3.8, it is evident that Z4 cannot be greater than Z1 as the combined pressure diagram will not reflect the actual pressure distribution of Figure 3.2(b). The user must input a new depth, preferably two to three times greater than originally assumed. Input an estimated depth according to Table 3.3.

Table 3.3. Recommended Assumed Wall Depths.

N(Sand)	Clay	(Cu, PSF)	Depth (SF = 1)
0 - 4	Soft	(250- 500)	2.0H
5 - 10	Firm	(500 - 1000)	1.5H
11 - 30	Stiff	(1000 - 1500)	1.25H
31 - 50	Very Stiff	(1500 - 2000)	1.H
50+	Hard	(>2000)	.25 H

Although the number of moment iterations may be reduced in half by specifying a depth close to the required depth, it will many times reduce actual user time by inputting a seemingly large assumed depth. Doing so, the warning will not appear and the program will iterate the required depth in a relatively short time.

When the condition:

$$4c - q < 0$$

where,

q = surcharge on soil #2

c = cohesion of soil #2

is satisfied the passive pressure below the dredge line is always less than the active pressure (Figure 3.14). Therefore, an equilibrium condition cannot be achieved no matter how deep the sheet piling is driven below the dredge line. This condition may occur in soft and very soft clays typically having undrained shear strengths less than about 500 psf.

The program identifies this condition when P1 is calculated as a positive number (see Figure 3.8). Upon idenfification of this condition, the statement "*Warning* Computed Wall Instability" is printed on the monitor. The user is given the option to end the program or to re-enter the input variables. The first correction would be to reduce the safety factor to one. If the program successfully runs,

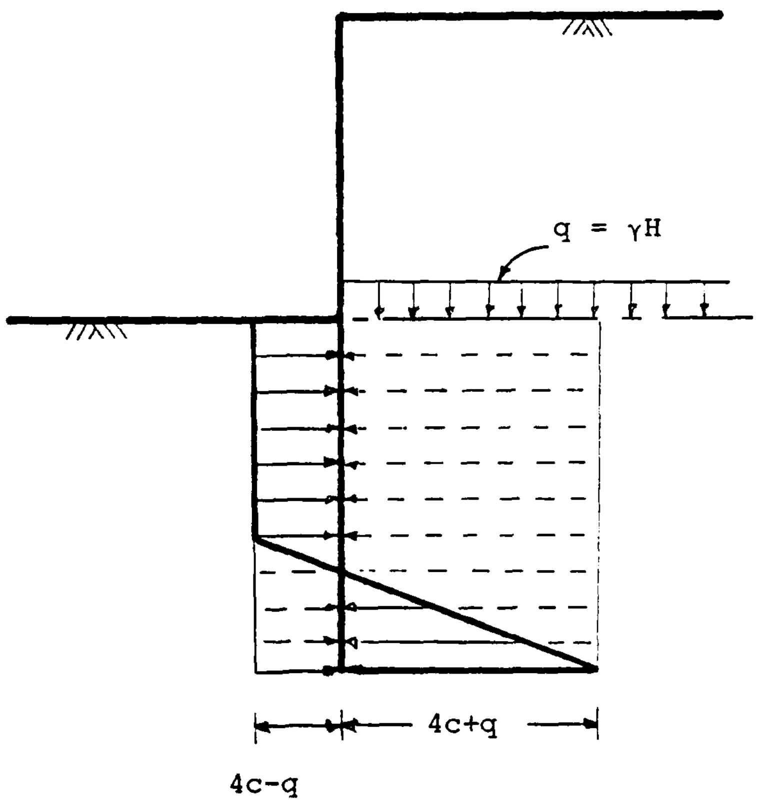


Figure 3.14. Quick, Undrained Loading in Cohesive Soil.

increase the depth by 20% to 40% [2]. The second correction should be to decrease the wall height thus decreasing the value of "q." If all else fails, the user must change the soil conditions in soil #2 or abort the design completely.

The final warning advises the user that soil #1 is in tension and does not mobilize an active force on the wall. This will occur when soil #1 is specified to have large cohesive characteristics. As described in Section 3.2, this phenomena occurs when the cohesive effects of the soil are great enough to allow the soil to stand

unsupported to a height equal to or greater than the specified wall height.

The only way to avoid this condition is to increase the wall height thus increasing the active force on the wall due to soil weight, or decrease the cohesive characteristic of the soil.

3.4.9 Limitations

The limitations of CANTWALL relate primarily to the physical description of the conditions. The most severe limitation is not being capable to specify a surcharge load on the backfill (soil #1). Many practical applications would warrant a surcharge. If a surcharge exists, the user can decrease the cohesion in soil #1 and soil #2 by an appropriate amount such that the net effect on the wall is the same. Since the cohesion creates a rectangular pressure diagram as does a surcharge, this could be done.

A negative cohesion may be input to simulate a surcharge in a cohesionless backfill. The user must convert the surcharge to a proper value of cohesion by the following analogy:

$$\sigma_a^{c'} = -2c'\sqrt{ka} \qquad \text{cohesion}$$

$$\sigma_a^{q} = q\ ka \qquad \text{surcharge}$$

$$\therefore \quad c' = -q\sqrt{ka}/2$$

where,

σ_a^c = active earth pressure due to cohesion

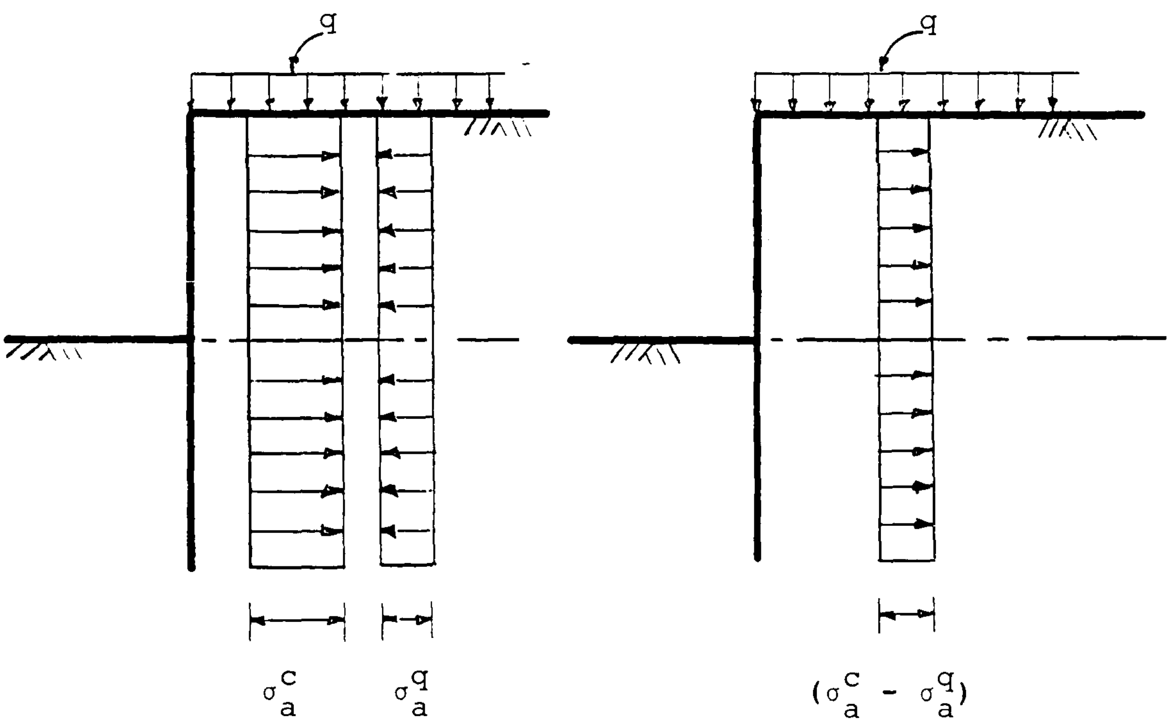
σ_a^q = active earth pressure due to surcharge

c' = equivalent cohesion

q = surcharge

k_a = active earth pressure coefficient

In a cohesive soil, the equivalent cohesion is added to the cohesion of soil #1 and soil #2. The user must maintain a consistent sign convention. See Figure 3.15.



(a) Active pressures due to cohesion and surcharge

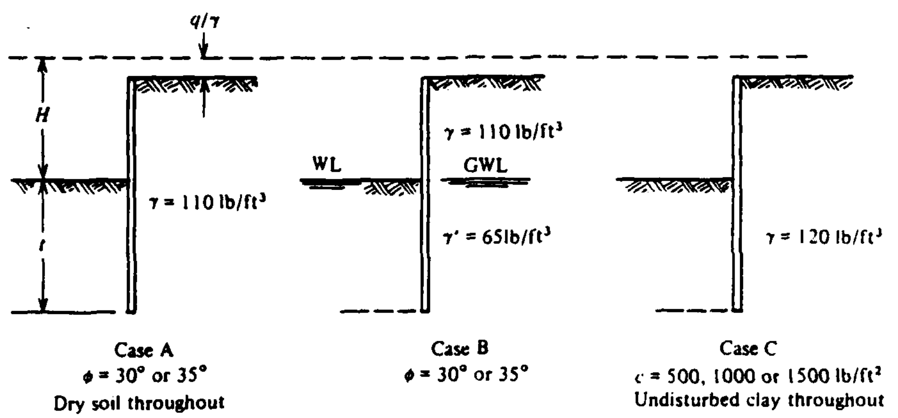
(b) Equivalent cohesion

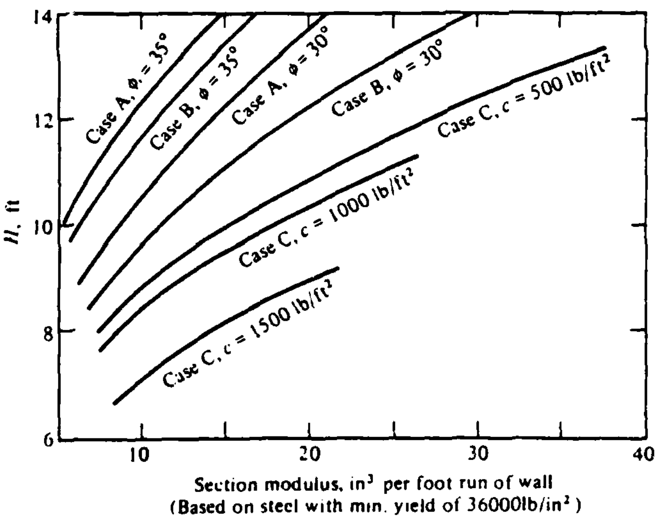
Figure 3.15. Surcharge Represented by Equivalent Cohesion in a Cohesive Soil.

Another limitation is the predetermination of soil layers. Although the user may easily specify a homogeneous condition, the user is limited to two soil types separated at a predetermined depth. Engineering judgment is the only guide in this case.

The calculated method used in this program assumes a rigid wall and therefore no effects of moment redistribution attributed to wall flexibility are considered.

The final limitation is contingent upon the fact that any cantilevered structure is limited in length or depth by the large bending moments developed under load. In general, heights exceeding 15 to 20 ft are infeasible. Construction materials with section moduli high enough to withstand the bending moments become uneconomical compared to the cost of material used in alternate construction techniques such as anchored walls [1]. This is an engineering decision. The supplementary data list contains the necessary data to calculate the bending moments in the wall. Figure 3.16 provides an insight into the section moduli required to resist loads imposed under three cases.





q is surcharge in lb/ft²

		Values of t/H
Case A	$\phi = 30°$	1.0
	$\phi = 35°$	1.0
Case B	$\phi = 30°$	1.35
	$\phi = 35°$	1.15
Case C	$c = 500$ lb/ft²	*
	$c = 1000$ lb/ft²	1.0
	$c = 1500$ lb/ft²	1.0

*$t/H = 1.5$ when $H = 7.5'$
$= 2.3$ when $H = 9.5'$

Figure 3.16. Cantilevered Walls [5].

3.5 Program List

```
5  SPEED= 150
10  PRINT "           **********"
11  PRINT "           *CANTWALL*"
12  PRINT "           **********"
13  PRINT : PRINT : PRINT
20  PRINT " DANA K. EDDY"
22  PRINT " GA. INSTITUTE OF TECHNOLOGY"
24  PRINT " SCHOOL OF CIVIL ENGINEERING"
26  PRINT " DEPARTMENT OF GEOTECHNICAL ENGINEERING"
30  PRINT : PRINT : PRINT
35  PRINT " SYSTEM HARDWARE: APPLE II PLUS (64K)
36  PRINT " SYSTEM SOFTWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE"
37  PRINT " PROGRAM DATE: MAY, 1983"
40  PRINT : PRINT : PRINT : PRINT
45  PRINT " CANTWALL ESTIMATES THE EMBEDMENT DEPTH OF A CANTILEVERED WALL.
      THE FREE EARTH SUPPORT METHOD IS USED. THE WALL IS ASSUMED RIGID."
50  PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
55  SPEED= 255
470  PRINT "HOW MANY PROBLEM SETS DO YOU WANT TO RUN?"
480  INPUT Q
485  DIM A(88): DIM B(88)
486  DIM C(88): DIM D(88)
490  FOR R = 1 TO Q
491  PRINT : PRINT
495 AD = 0
500  PRINT "WHAT IS THE WET WEIGHT OF SOIL #1? (PCF)"
510  INPUT G1
511  PRINT : PRINT
520  PRINT "WHAT IS THE SATURATED WEIGHT OF SOIL #1? (PCF)"
530  INPUT G2
531  PRINT : PRINT
534  PRINT "WHAT IS THE COHESION OF SOIL #1? (PSF)"
538  INPUT C1
539  PRINT : PRINT
542  PRINT "WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #1? (DEGREES)"

546  INPUT A1
547  PRINT : PRINT
550  PRINT "WHAT IS THE FRICTION ANGLE BETWEEN THE WALL AND SOIL #1? (DEGR
     EES)"
554  INPUT B1
555  PRINT : PRINT
558  PRINT "WHAT IS THE WET WEIGHT OF SOIL #2? (PCF)"
562  INPUT G3
```

```
563  PRINT : PRINT
566  PRINT "WHAT IS THE SATURATED WEIGHT OF SOIL #2? (PCF)"
570  INPUT G4
571  PRINT : PRINT
574  PRINT "WHAT IS THE COHESION OF SOIL #2? (PSF)"
578  INPUT C2
579  PRINT : PRINT
582  PRINT "WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #2? (DEGREES)"

586  INPUT A2
587  PRINT : PRINT
590  PRINT "WHAT IS THE FRICTION ANGLE FOR THE WALL AND SOIL #2? (DEGREES)
     "
595  INPUT B2
596  PRINT : PRINT
600  PRINT "WHAT IS THE HEIGHT OF THE WALL? (FEET)"
605  INPUT Z2
606  PRINT : PRINT
610  PRINT "WHAT IS THE DEPTH OF THE GROUND WATER TABLE? (FEET)"
615  INPUT Z3
616  PRINT : PRINT
620  PRINT "WHAT IS THE TOLERANCE FOR DEPTH CALCULATION (PERCENT, REC'D .1
      - .01)?"
625  INPUT TL
626  PRINT : PRINT
630  PRINT "WHAT IS THE SAFETY FACTOR"
635  INPUT SF
636  PRINT : PRINT
640  PRINT "DO YOU WANT TENSION CRACKS WITH WATER PRESSURE TO BE CONSIDERE
     D IN SOIL #1? (YES OR NO)"
645  INPUT A$:X =  ASC (A$): IF X < 84 GOTO 671
646  IF X < 84 GOTO 671
647  PRINT : PRINT
650 Z7 = 2 * C1 / G1
655  IF Z7 < Z3 GOTO 665
660 Z7 = Z2
665  IF Z7 < Z2 GOTO 671
670 Z7 = Z2
671  PRINT : PRINT : PRINT "DO YOU WANT TO USE AN EQUIVALENT ACTIVE FORCE
     IN SOIL #1? (YES OR NO)"
672  INPUT C$:W =  ASC (C$)
673  PRINT : PRINT
675  PRINT "DO YOU WANT TO INPUT THE COEFFICIENTS OF EARTH PRESSURE (YES)
     OR HAVE THEM CALCULATED FOR YOU (NO)?"
680  INPUT B$:X =  ASC (B$): IF X < 84 GOTO 725
681  IF X < 84 GOTO 725
682  PRINT : PRINT : PRINT
685  PRINT "WHAT IS K ACTIVE FOR SOIL #1?"
690  INPUT K1
691  PRINT
```

```
695  PRINT "WHAT IS K PASSIVE FOR SOIL #2?"
700  INPUT K2
701. PRINT
705  PRINT "WHAT IS K ACTIVE FOR SOIL #2?"
710  INPUT K3
715  GOTO 744
725 RA = .01745
730 K1 = ( SIN (1.571 + A1 * RA)) ^ 2 /  SIN (1.571 - B1 * RA) / (1 + ( SIN
     ((A1 + B1) * RA) *  SIN (A1 * RA) /  SIN (1.571 - B1 * RA)) ^ .5) ^ 2

735 K2 = ( SIN (1.571 - A2 * RA)) ^ 2 /  SIN (1.571 + B2 * RA) / (1 - ( SIN
     ((A2 + B2) * RA) *  SIN (A2 * RA) /  SIN (1.571 - B2 * RA)) ^ .5) ^ 2

740 K3 = ( SIN (1.571 + A2 * RA)) ^ 2 /  SIN (1.571 - B2 * RA) / (1 + ( SIN
     ((A2 + B2) * RA) *  SIN (A2 * RA) /  SIN (1.571 - B2 * RA)) ^ .5) ^ 2

744 G5 = 62.4
745  PRINT : PRINT
746  IF Z3 > Z2 GOTO 747:Z8 = 2 * C1 * K1 ^ .5 * Z2 / ((G1 * Z3 + (G2 - G5
     ) * (Z2 - Z3)) * K1): IF Z8 < Z2 GOTO 750: GOTO 748
747 Z8 = 2 * C1 / (G1 * K1 ^ .5): IF Z8 < Z2 GOTO 760
748  PRINT "SOIL #1 IS IN TENSION, REEVALUATE THE COHESION OF SOIL #1 OR T
     HE HEIGHT OF THE WALL.  TYPE (1) TO RESTART THE PROGRAM."
749  INPUT AB: GOTO 491
760  PRINT "INPUT ASSUMED DEPTH OF WALL PENETRATION (REFER TO USERS' MANUA
     L)."
762  INPUT Z1
763  PRINT : PRINT
764 N = 1
770 Z4 = .72 * Z1: GOTO 774
771  PRINT "ASSUMED DEPTH MUST BE INCREASED": PRINT : PRINT
772 AZ = 0: GOTO 760
774 F1 = 0:F2 = 0:F3 = 0:F4 = 0:F5 = 0:F6 = 0:F7 = 0:F8 = 0:F9 = 0:F0 = 0:
     LA = 0:LB = 0:LC = 0:LD = 0:LE = 0:LF = 0:LG = 0:LH = 0:LI = 0:LJ = 0

775 M = 1
780  IF Z3 > Z2 GOTO 930
781  IF W < 84 GOTO 785
782 F1 = ((G1 * Z3 + (G2 - G5) * (Z2 - Z3)) * K1 - 2 * C1 * K1 ^ .5) * (Z2
      - 2 * C1 * K1 ^ .5 * Z2 / (G1 * Z3 + (G2 - G5) * (Z2 - Z3)) / K1) /
     2
783  GOTO 805
785 F1 = G1 * Z3 ^ 2 * K1 / 2
790 F2 = G1 * Z3 * K1 * (Z2 - Z3)
795 F3 = (G1 * Z3 + (G2 - G5) * (Z2 - Z3) - G1 * Z3) * K1 * (Z2 - Z3) / 2
800 F4 =  - 2 * C1 * K1 ^ .5 * Z2
805 F5 = G5 * (Z2 - Z3) ^ 2 / 2
810 F6 = G5 * Z7 ^ 2 / 2
815 FA = F1 + F2 + F3 + F4 + F5 + F6
```

```
816  IF FA > 0 GOTO 845
817  PRINT "** WARNING **     THE NET ACTIVE FORCE AGAINST THE WALL IN SOI
     L #1 IS NEGATIVE."
818. PRINT : PRINT
819  PRINT "TO RESTART THE PROGRAM TYPE (1); TO EXERCISE SOIL #1 ACTIVE OP
     TIONS TYPE (2)."
820  INPUT AA: IF AA = 1 GOTO 491: GOTO 636
821  GOTO 636
845 Z = Z1
850  GOSUB 6200
855 Z = Z4
860  GOSUB 6100
865 P1 = PL
866  GOSUB 6800
867  IF AD = 1 GOTO 491
870 Z = 0
875  GOSUB 6100
880 P2 = PL
885  GOSUB 4000
886  IF AZ = 1 GOTO 771
887  IF M = 1 GOTO 894
890  IF TL >  =  ABS (100 * (Z4 - C(M)) / Z4) GOTO 896
894 M = M + 1
895  GOTO 855
896  IF W < 84 GOTO 900
897 LA = Z5 + Z2 / 3
898  GOTO 917
900 LA = Z5 + Z2 - 2 * Z3 / 3
910 LB = Z5 + (Z2 - Z3) / 2
915 LC = Z5 + (Z2 - Z3) / 3
916 LD = Z5 + Z2 / 2
917 LE = Z5 + (Z2 - Z3) / 3
918 LF = Z5 + Z2 - 2 * Z7 / 3
920  GOSUB 6000
921  IF N = 1 GOTO 923
922  IF TL >  =  ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
923 N = N + 1
925  GOTO 770
930  IF Z3 > Z2 + Z1 GOTO 2331
931  IF W < 84 GOTO 935
932 F1 = (Z2 * G1 * K1 - 2 * C1 * K1 ^ .5) * (Z2 - 2 * C1 / (G1 * K1 ^ .5)
     ) / 2
933  GOTO 945
935 F1 = G1 * Z2 ^ 2 * K1 / 2
940 F2 =  - 2 * C1 * K1 ^ .5 * Z2
945 F3 = G5 * Z7 ^ 2 / 2
950 FA = F1 + F2 + F3
951  IF FA > 0 GOTO 965
952  PRINT "** WARNING **     THE NET ACTIVE FORCE AGAINST THE WALL IN SOI
     L #1 IS NEGATIVE."
```

```
953  PRINT : PRINT
954  PRINT " TO RESTART THE PROGRAM TYPE (1); TO EXERCISE SOIL #1 ACTIVE O
     PTIONS TYPE (2)."
955  INPUT AB: IF AB = 1 GOTO 491: GOTO 636
956  GOTO 636
965  IF Z4 <  = Z3 - Z2 GOTO 2010
970 Z = Z1
975  GOSUB 6400
980 Z = Z4
985  GOSUB 6300
990 P1 = PL
991  GOSUB 6800
992  IF AD = 1 GOTO 491
995 Z5 = Z1 - (PR * (Z4 - Z1) / (P1 - PR))
1000 Z = Z3 - Z2
1005  GOSUB 6300
1010 P3 = PL
1015 Z = 0
1020  GOSUB 6700
1025 P2 = PL
1030  IF P2 > 0 GOTO 1120
1035 F4 = P2 * (Z3 - Z2)
1040 F5 = (P3 - P2) * (Z3 - Z2) / 2
1045 F6 = (P1 - P3) * (Z4 - Z3 + Z2) / 2
1050 F7 = P3 * (Z4 - Z3 + Z2)
1055 F8 = P1 * (Z5 - Z4) / 2
1060 F9 = PR * (Z1 - Z5) / 2
1065  GOSUB 5000
1066  IF AZ = 1 GOTO 771
1067  IF M = 1 GOTO 1074
1070  IF TL >  =  ABS (100 * (Z4 - C(M)) / Z4) GOTO 1080
1074 M = M + 1
1075  GOTO 980
1080 LA = Z5 + Z2 / 3
1081  IF W > 84 GOTO 1086
1085 LB = Z5 + Z2 / 2
1086 LC = Z5 + Z2 - 2 * Z7 / 3
1087 LD = Z5 - (Z3 - Z2) / 2
1088 LE = Z5 - 2 * (Z3 - Z2) / 3
1089 LF = Z5 - (Z3 - Z2 + 2 * Z4) / 3
1090 LG = Z5 - (Z3 - Z2 + Z4) / 2
1091 LH = 2 * (Z5 - Z4) / 3
1095 LI =  - 2 * (Z1 - Z5) / 3
1110  GOSUB 6000
1111  IF N = 1 GOTO 1113
1112  IF TL >  =  ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
1113 N = N + 1
1115  GOTO 770
1120 Z6 = (Z3 - Z2) * P2 / (P2 - P3)
1122  IF Z6 > (Z3 - Z2) GOTO 1200
```

```
1125 F4 = P2 * Z6 / 2
1130 F5 = P3 * (Z3 - Z2 - Z6) / 2
1135 F6 = (P1 - P3) * (Z4 - Z3 + Z2) / 2
1140 F7 = P3 * (Z4 - Z3 + Z2)
1145 F8 = P1 * (Z5 - Z4) / 2
1150 F9 = PR * (Z1 - Z5) / 2
1155  GOSUB 5000
1156  IF AZ = 1 GOTO 771
1157  IF M = 1 GOTO 1164
1160  IF TL >  =  ABS (100 * (Z4 - C(M)) / Z4) GOTO 1170
1164 M = M + 1
1165  GOTO 980
1170 LA = Z5 + Z2 / 3
1171  IF W > 84 GOTO 1173
1172 LB = Z5 + Z2 / 2
1173 LC = Z5 + Z2 - 2 * Z7 / 3
1174 LD = Z5 - Z6 / 3
1175 LE = Z5 - (Z6 + 2 * Z3 - 2 * Z2) / 3
1180 LF = Z5 - 2 * (Z4 - Z3 + Z2) / 3
1185 LG = Z5 - (Z4 - Z3 + Z2) / 2
1190 LH = (2 * Z5 + Z4) / 3
1195 LI =  - 2 * (Z1 - Z5) / 3
1197  GOTO 2000
1200 F4 = P3 * (Z3 - Z2)
1205 F5 = (P2 - P3) * (Z3 - Z2) / 2
1210 F6 = P3 * (Z6 - Z3 + Z2) / 2
1215 F7 = P1 * (Z4 - Z6) / 2
1220 F8 = P1 * (Z5 - Z4) / 2
1225 F9 = PR * (Z1 - Z5) / 2
1230  GOSUB 5000
1232  IF AZ = 1 GOTO 771
1235  IF TL >  =  ABS (100 * (Z4 - C(M)) / Z4) GOTO 1250
1240 M = M + 1
1245  GOTO 980
1250 LA = Z5 + Z2 / 3
1255  IF W > 84 GOTO 1265
1260 LB = Z5 + Z2 / 2
1265 LC = Z5 + Z2 - 2 * Z7 / 3
1270 LD = Z5 - (Z3 - Z2) / 2
1275 LE = Z5 - (Z3 - Z2) / 3
1280 LF = Z5 + (2 * Z2 - 2 * Z3 - Z6) / 3
1285 LG = Z5 - 2 * (Z4 - Z6) / 3
1290 LH = 2 * (Z5 - Z4) / 3
1295 LI =  - 2 * (Z1 - Z5) / 3
1300  GOSUB 6000
1305  IF N = 1 GOTO 1315
1310  IF TL >  =  ABS (100 * (Z1 [illegible](N)) / Z1) GOTO 3000
1315 N = N + 1
1320  GOTO 770
2000  GOSUB 6000
```

```
2001  IF N = 1 GOTO 2003
2002  IF TL >  =  ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
2003 N = N + 1
2005  GOTO 770
2010 Z = Z1
2015  GOSUB 6400
2020 Z = Z4
2025  GOSUB 6700
2030 P1 = PL
2031  GOSUB 6800
2032  IF AD = 1 GOTO 491
2035 Z = 0
2040  GOSUB 6700
2045 P2 = PL
2050  GOSUB 4000
2051  IF AZ = 1 GOTO 771
2052  IF M = 1 GOTO 2059
2055  IF TL >  =  ABS (100 * (Z4 - C(M)) / Z4) GOTO 2065
2059 M = M + 1
2060  GOTO 2020
2065 LA = Z5 + Z2 / 3
2066  IF W > 84 GOTO 2075
2070 LB = Z5 + Z2 / 2
2075 LC = Z5 + Z2 - 2 * Z7 / 3
2085  GOSUB 6000
2086  IF N = 1 GOTO 2088
2087  IF TL >  =  ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
2088 N = N + 1
2090  GOTO 770
2331  IF W < 84 GOTO 2335
2332 F1 = (Z2 * G1 * K1 - 2 * C1 * K1 ^ .5) * (Z2 - 2 * C1 / (G1 * K1 ^ .5
      )) / 2
2333  GOTO 2345
2335 F1 = G1 * Z2 ^ 2 * K1 / 2
2340 F2 =  - 2 * C1 * K1 ^ .5 * Z2
2345 F3 = G5 * Z7 ^ 2 / 2
2350 FA = F1 + F2 + F3
2351  IF FA > 0 GOTO 2365
2352  PRINT "** WARNING **     THE NET ACTIVE FORCE AGAINST THE WALL IN SO
      IL #1 IS NEGATIVE."
2353  PRINT : PRINT
2354  PRINT "TO RESTART THE PROGRAM TYPE (1); TO EXERCISE SOIL #1 ACTIVE O
      PTIONS TYPE (2)."
2355  INPUT AC: IF AC = 1 GOTO 491: GOTO 636
2356  GOTO 636
2365 Z = Z1
2370  GOSUB 6600
2375 Z = Z4
2380  GOSUB 6500
2385 P1 = PL
```

```
2386  GOSUB 6800
2387  IF AD = 1 GOTO 491
2390 Z = 0
2395  GOSUB 6500
2400 P2 = PL
2405  GOSUB 4000
2406  IF AZ = 1 GOTO 771
2407  IF M = 1 GOTO 2414
2410  IF TL >  =  ABS (100 * (Z4 - C(M)) / Z4) GOTO 2420
2414 M = M + 1
2415  GOTO 2375
2420 LA = Z5 + Z2 / 3
2421  IF W > 84 GOTO 2430
2425 LB = Z5 + Z2 / 2
2430 LC = Z5 + Z2 - 2 * Z7 / 3
2440  GOSUB 6000
2441  IF N = 1 GOTO 2443
2442  IF TL >  =  ABS (100 * (Z1 - A(N)) / Z1) GOTO 3000
2443 N = N + 1
2445  GOTO 770
3000 L$ =  CHR$ (4): PRINT L$;"PR#1"
3008  PRINT "**********": PRINT "**********"
3010  PRINT "INPUT DATA"
3011  PRINT "**********": PRINT "**********"
3012  PRINT : PRINT
3020  PRINT "WET UNIT WEIGHT, SOIL #1 ="G1" PCF."
3021  PRINT
3030  PRINT "SATURATED UNIT WEIGHT, SOIL #1 ="G2" PCF."
3031  PRINT
3040  PRINT "COHESION, SOIL #1 ="C1" PSF."
3041  PRINT
3050  PRINT "ANGLE OF INTERNAL FRICTION, SOIL #1 ="A1" DEGREES."
3051  PRINT
3060  PRINT "FRICTION ANGLE, SOIL #1 ="B1" DEGREES."
3061  PRINT
3070  PRINT "WET UNIT WEIGHT, SOIL #2 ="G3" PCF."
3071  PRINT
3080  PRINT "SATURATED UNIT WEIGHT, SOIL #2 ="G4" PCF."
3081  PRINT
3090  PRINT "COHESION, SOIL #2 ="C2" PSF."
3091  PRINT
3100  PRINT "ANGLE OF INTERNAL FRICTION, SOIL #2 ="A2" DEGREES."
3101  PRINT
3110  PRINT "FRICTION ANGLE, SOIL #2 ="B2" DEGREES."
3111  PRINT
3120  PRINT "WALL HEIGHT ="Z2" FEET."
3121  PRINT
3130  PRINT " GROUND WATER DEPTH ="Z3" FEET."
3131  PRINT
3133  PRINT "ACTIVE K, SOIL #1 ="K1
```

```
3134  PRINT
3135  PRINT "PASSIVE K, SOIL #2 ="K2
3136  PRINT
3137  PRINT "ACTIVE K, SOIL #2 ="K3
3138  PRINT
3140  PRINT "TOLERANCE ="TL" PERCENT."
3141  PRINT
3150  PRINT "SAFETY FACTOR ="SF"."
3151  PRINT : PRINT
3158  PRINT "***********": PRINT "***********"
3160  PRINT "OUTPUT DATA"
3161  PRINT "***********": PRINT "***********"
3162  PRINT : PRINT
3165 ZZ = Z1 * 100
3166 ZZ =  INT (ZZ)
3167 ZZ = ZZ / 100
3170  PRINT "REQUIRED WALL PENETRATION ="ZZ" FEET."
3171  PRINT : PRINT
3180  PRINT L$;"PR#0"
3190  PRINT : PRINT : PRINT "DO YOU WANT SUPPLEMENTARY DATA?"
3200  INPUT C$:X =  ASC (C$): IF X < 84 GOTO 3520
3210 L$ =  CHR$ (4): PRINT L$;"PR#1"
3218  PRINT
3219  PRINT "******************"
3220  PRINT "SUPPLEMENTARY DATA"
3221  PRINT "******************"
3222  PRINT : PRINT
3225  PRINT "Z1 ="Z1" FEET."
3230  PRINT "Z4 ="Z4" FEET."
3240  PRINT "Z5 ="Z5" FEET."
3250  PRINT "Z6 ="Z6" FEET."
3260  PRINT "Z7 ="Z7" FT."
3270  PRINT "P1 ="P1" PSF."
3280  PRINT "P2 ="P2" PSF."
3290  PRINT "P3 ="P3" PSF."
3300  PRINT "P4 ="P4" PSF."
3400  PRINT "PR ="PR" PSF."
3405  PRINT "F1 ="F1"#.          ","LA ="LA"FT."
3410  PRINT "F2 ="F2"#.          ","LB ="LB"FT."
3415  PRINT "F3 ="F3"#.          ","LC ="LC"FT."
3420  PRINT "F4 ="F4"#.          ","LD ="LD"FT."
3425  PRINT "F5 ="F5"#.          ","LE ="LE"FT."
3430  PRINT "F6 ="F6"#.          ","LF ="LF"FT."
3435  PRINT "F7 ="F7"#.          ","LG ="LG"FT."
3440  PRINT "F8 ="F8"#.          ","LH ="LH"FT."
3445  PRINT "F9 ="F9"#.          ","LI ="LI"FT."
3450  PRINT "F0 ="F0"#.          ","LJ ="LJ"FT."
3460  PRINT "FT ="FT"#.          ","MT ="MT"FT-#."
3500  PRINT L$;"PR#0"
3505  HOME
```

```
3510  NEXT R
3520  PRINT "THANK YOU FOR USING CANTWALL."
3521  PRINT
3522  PRINT "BYE-BYE"
3523  END
4000 Z5 = Z1 - (PR * (Z4 - Z1) / (P1 - PR))
4005  IF P2 >  = 0 GOTO 4040
4010 F7 = P2 * Z4
4015 F8 = (P1 - P2) * Z4 / 2
4020 F9 = P1 * (Z5 - Z4) / 2
4025 F0 = PR * (Z1 - Z5) / 2
4026 LG = Z5 - Z4 / 2
4027 LH = Z5 - 2 * Z4 / 3
4028 LI = 2 * (Z5 - Z4) / 3
4029 LJ =  - 2 * (Z1 - Z5) / 3
4030  GOSUB 5000
4035  RETURN
4040 Z6 =  - P2 * Z4 / (P1 - P2)
4045 F7 = P2 * Z6 / 2
4050 F8 = P1 * (Z4 - Z6) / 2
4055 F9 = P1 * (Z5 - Z4) / 2
4060 F0 = PR * (Z1 - Z5) / 2
4061 LG = Z5 - Z6 / 3
4062 LH = Z5 - (2 * Z4 + Z6) / 3
4063 LI = 2 * (Z5 - Z4) / 3
4064 LJ =  - 2 * (Z1 - Z5) / 3
4065  GOSUB 5000
4070  RETURN
5000 FT = F1 + F2 + F3 + F4 + F5 + F6 + F7 + F8 + F9 + F0
5005 C(M) = Z4
5010 D(M) = FT
5015  IF M >  = 2 GOTO 5055
5020  IF D(M) < 0 GOTO 5040
5025 Z4 = Z4 + 2
5035  RETURN
5040 Z4 = Z4 - 2
5050  RETURN
5055 Z4 = C(M - 1) - D(M - 1) * (C(M) - C(M - 1)) / (D(M) - D(M - 1
5056  IF Z4 <  = Z1 THEN 5065
5060 AZ = 1
5065  RETURN
6000 MT = F1 * LA + F2 * LB + F3 * LC + F4 * LD + F5 * LE + F6 * LF + F7 *
     LG + F8 * LH + F9 * LI + F0 * LJ
6001  PRINT "I AM COMPUTING, PLEASE BE PATIENT.": PRINT : PRINT
6005 A(N) = Z1
6010 B(N) = MT
6015  IF N >  = 2 GOTO 6055
6020  IF B(N) < 0 GOTO 6040
6025 Z1 = Z1 + 2
6035  RETURN
```

```
6040 Z1 = Z1 - 2
6050  RETURN
6055 Z1 = A(N - 1) - B(N - 1) * (A(N) - A(N - 1)) / (B(N) - B(N - 1))
6070  RETURN
6100 PL =  - ((G4 - G5) * Z * K2 + 2 * C2 * K2 ^ .5 + G5 * Z) / SF + (G4 -
     G5) * Z * K3 + (G1 * Z3 + (G2 - G5) * (Z2 - Z3)) * K3 + G5 * (Z2 - Z3
      + Z) - 2 * C2 * K3 ^ .5
6105  RETURN
6200 PR = ((G4 - G5) * Z * K2 + 2 * C2 * K2 ^ .5 + (G1 * Z3 + (G2 - G5) *
     (Z2 - Z3)) * K2 + G5 * (Z2 - Z3 + Z)) / SF + 2 * C2 * K3 ^ .5 - (G4 -
     G5) * Z * K3 - G5 * Z
6205  RETURN
6300 PL =  - (2 * C2 * K2 ^ .5 + G3 * (Z3 - Z2) * K2 + G5 * (Z - Z3 + Z2) +
     (G4 - G5) * (Z - Z3 + Z2) * K2) / SF + G3 * (Z3 - Z2) * K3 - 2 * C2 *
     K3 ^ .5 + G5 * (Z - Z3 + Z2) + (G4 - G5) * (Z - Z3 + Z2) * K3 + G1 *
     Z2 * K3
6305  RETURN
6400 PR = (G3 * (Z3 - Z2) * K2 + 2 * C2 * K2 ^ .5 + G1 * Z2 * K2 + (G4 - G
     5) * (Z - Z3 + Z2) * K2 + G5 * (Z - Z3 + Z2)) / SF + 2 * C2 * K3 ^ .5
      - G3 * (Z3 - Z2) * K3 - (G4 - G5) * (Z - Z3 + Z2) * K3 - G5 * (Z - Z
     3 + Z2)
6405  RETURN
6500 PL =  - (G3 * Z * K2 + 2 * C2 * K2 ^ .5) / SF + G3 * Z * K3 - 2 * C2 *
     K3 ^ .5 + G1 * Z2 * K3
6505  RETURN
6600 PR = (G3 * Z * K2 + 2 * C2 * K2 ^ .5 + G1 * Z2 * K2) / SF + 2 * C2 *
     K3 ^ .5 - G3 * Z * K3
6605  RETURN
6700 PL =  - (G3 * Z * K2 + 2 * C2 * K2 ^ .5) / SF + G3 * Z * K3 - 2 * C2 *
     K3 ^ .5 + G1 * Z2 * K3
6705  RETURN
6800  IF P1 < 0 GOTO 6835
6805  PRINT : PRINT
6810  PRINT "** WARNING **   COMPUTED WALL INSTABILITY (SEE USERS' MANUAL)
     "
6815  PRINT : PRINT
6820  PRINT "TO RESTART THE PROGRAM TYPE (1); TO END THE PROGRAM TYPE (2)"

6825  INPUT AD: IF AD = 1 GOTO 6835
6830  END
6835  RETURN
```

3.6 Variable List (CANTWALL 1)

Input

Q = # of runs

G1 = Wet weight, soil #1

G2 = Saturated weight, soil #2

C1 = Cohesion, soil #1

A1 = Phi angle, soil #1

B1 = Delta angle, soil #1

G3 = Wet weight, soil #2

G4 = Saturated weight, soil #2

C2 = Cohesion, soil #2

A2 = Phi angle, soil #2

B2 = Delta angle, soil #2

Z2 = Wall height

Z3 = Depth to GWT

TL = Tolerance

SF = Safety factor

K1 = Active earth pressure coefficient, soil #1

K2 = Passive earth pressure coefficient, soil #2

K3 = Active earth pressure coefficient, soil #2

Flow Control

AZ = Z4 > Z1

X = Question input

W = Equivalent active force in soil #1

AB = Restart or end program

AA = Restart or end program

AC = Restart or end program

AD = Restart or end program

Counters

R = Run number

N = Moment iterations

M = Force iterations

Miscellaneous

Z1 = Wall penetration depth

Z4 = Pressure depth in soil #2

Z5 = Pressure depth in soil #2

Z6 = Pressure depth in soil #2

Z7 = Tension crack depth in soil #1

Z8 = Tension depth in soil #1

Z = Depth

G5 = Unit weight of water, 62.4 pcf

F1-F0 = Forces

LA-LJ = Lever arms

FA = Σ forces in soil #1

FT = Σ forces, total

MT = Σ moments

C(M) = Z4

D(M) = FT

A(N) = Z1

B(N) = MT

P1-P3 = Soil pressures, soil #2

PR = Soil pressure, soil #2

3.7 Problem Verification

3.7.1 Problem #1

```
HOW MANY PROBLEM SETS DO YOU WANT TO RUN?
?3

WHAT IS THE WET WEIGHT OF SOIL #1? (PCF)
?110

WHAT IS THE SATURATED WEIGHT OF SOIL #1? (PCF)
?122.4

WHAT IS THE COHESION OF SOIL #1? (PSF)
?200

WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #1? (DEGREES)
?30

WHAT IS THE FRICTION ANGLE BETWEEN THE WALL AND SOIL #1? (DEGREES)
?15

WHAT IS THE WET WEIGHT OF SOIL #2? (PCF)
?110

WHAT IS THE SATURATED WEIGHT OF SOIL #2? (PCF)
?122.4

WHAT IS THE COHESION OF SOIL #2? (PSF)
?600

WHAT IS THE ANGLE OF INTERNAL FRICTION FOR SOIL #2? (DEGREES)
?30

WHAT IS THE FRICTION ANGLE FOR THE WALL AND SOIL #2? (DEGREES)
?15

WHAT IS THE HEIGHT OF THE WALL? (FEET)
?20

WHAT IS THE DEPTH OF THE GROUND WATER TABLE? (FEET)
?10
```

```
WHAT IS THE TOLERANCE FOR DEPTH CALCULATION (PERCENT, REC'D .1 - .01)?
?.05

WHAT IS THE SAFETY FACTOR
?1

DO YOU WANT TENSION CRACKS WITH WATER PRESSURE TO BE CONSIDERED IN SOIL #1? (YES
 OR NO)
?N

DO YOU WANT TO USE AN EQUIVALENT ACTIVE FORCE IN SOIL #1? (YES OR NO)
?N

DO YOU WANT TO INPUT THE COEFFICIENTS OF EARTH PRESSURE (YES) OR HAVE THEM CALCU
LATED FOR YOU (NO)?
?N

INPUT ASSUMED DEPTH OF WALL PENETRATION (REFER TO USERS' MANUAL).
?100

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.
```

```
I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

I AM COMPUTING, PLEASE BE PATIENT.

**********
**********
INPUT DATA
**********
**********

WET UNIT WEIGHT, SOIL #1 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #1 =122.4 PCF.

COHESION, SOIL #1 =200 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #1 =30 DEGREES.

FRICTION ANGLE, SOIL #1 =15 DEGREES.

WET UNIT WEIGHT, SOIL #2 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #2 =122.4 PCF.

COHESION, SOIL #2 =600 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #2 =30 DEGREES.

FRICTION ANGLE, SOIL #2 =15 DEGREES.

WALL HEIGHT =20 FEET.

 GROUND WATER DEPTH =10 FEET.

ACTIVE K, SOIL #1 =.301403678
```

PASSIVE K, SOIL #2 =4.97549393

ACTIVE K, SOIL #2 =.301403678

TOLERANCE =.05 PERCENT.

SAFETY FACTOR =1.

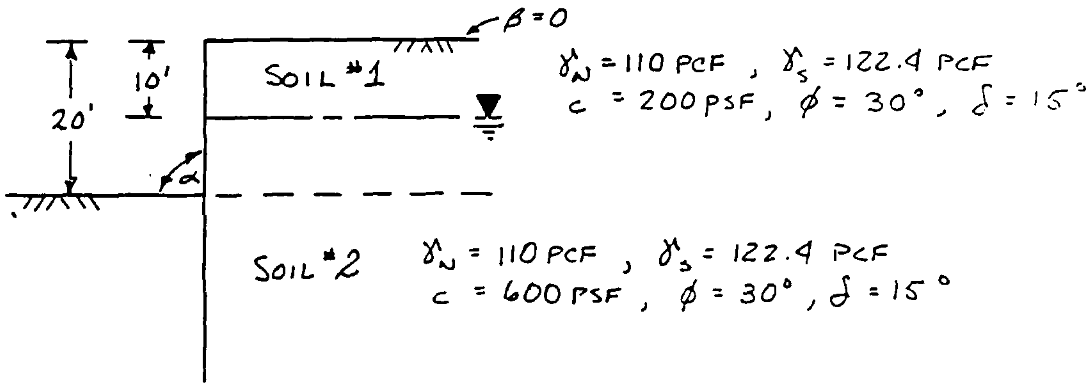
```
***********
***********
OUTPUT DATA
***********
***********
```

REQUIRED WALL PENETRATION =5.21 FEET.

DO YOU WANT SUPPLEMENTARY DATA?
?Y

```
******************
SUPPLEMENTARY DATA
******************
```

```
Z1 =5.21371744 FEET.
Z4 =3.99707472 FEET.
Z5 =4.23195843 FEET.
Z6 =0 FEET.
Z7 =0 FT.
P1 =-3320.07579 PSF.
P2 =-2199.1145 PSF.
P3 =0 PSF.
P4 =0 PSF.
PR =13880.0615 PSF.
F1 =1657.72023#.                LA =17.5652918FT.
F2 =3315.44046#.                LB =9.23195843FT.
F3 =904.211035#.                LC =7.56529176FT.
F4 =-4392.01951#.               LD =14.2319584FT.
F5 =3120#.                      LE =7.56529176FT.
F6 =0#.                         LF =24.2319584FT.
F7 =-8790.02499#.               LG =2.23342107FT.
F8 =-2240.283#.                 LH =1.56724195FT.
F9 =-389.915853#.               LI =.156589137FT.
F0 =6814.87162#.                LJ =-.654643747FT.
FT =-1.71661377E-05#.           MT =-1.62272716FT-#.
```



$$k_a^1 = \frac{\sin^2(\alpha+\phi)}{\sin^2\alpha \, \sin(\alpha-\delta)\left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\alpha-\delta)\sin(\alpha+\beta)}}\right]^2}$$

$$= \frac{\sin^2(90°+30°)}{\sin^2(90)\sin(90-15)\left[1+\sqrt{\frac{\sin(30+15)\sin(30-0)}{\sin(90-15)\sin(90+0)}}\right]^2}$$

$$= \underline{\underline{.3014}}$$

$$k_p^2 = \frac{\sin^2(\alpha-\phi)}{\sin^2\alpha \, \sin(\alpha+\delta)\left[1-\sqrt{\frac{\sin(\phi+\delta)\sin(\phi+\beta)}{\sin(\alpha+\delta)\sin(\alpha+\beta)}}\right]^2}$$

$$= \frac{\sin^2(90-30)}{\sin^2(90)\sin(90+15)\left[1-\sqrt{\frac{\sin(30+15)\sin(30+0)}{\sin(90+15)\sin(90+0)}}\right]^2}$$

$$= \underline{\underline{4.974}}$$

$$k_a^1 = k_a^2 = \underline{\underline{.3014}}$$

REFER TO FIGURE $(\div)$

$$F1 = k_a' \gamma (GWT)^2/2 = .3014 (110\ PCF)(10')^2/2 = \underline{1657.7^{\#}}$$

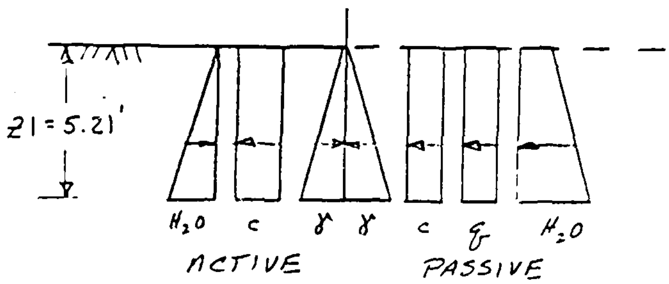
$$F2 = k_a' \gamma (GWT)(H-GWT) = .3014 (110)(10')(20'-10') = \underline{3315.4^{\#}}$$

$$F3 = k_a' \gamma' (H-GWT)^2/2 = .3014 (122.4-62.4)(20'-10')^2/2$$
$$= \underline{904.2^{\#}}$$

$$F4 = -2c\sqrt{k_a'} \cdot H = -2(200\ PSF)\sqrt{.3014}(20') = \underline{-4392.0^{\#}}$$

$$F5 = \gamma_{H_2O} (H-GWT)^2/2 = 62.4 (20'-10')^2/2 = \underline{3120^{\#}}$$

COMPOSITE PRESSURE @ $z1 = 5.21'$ (S.F = 1.0)



RIGHT SIDE (PASSIVE)

$$p_\gamma = \gamma'(z1) k_p^2 = (122.4-62.4)\ 5.21'(4.974) = \underline{1554.9^{\#}/Ft^2}$$
$$p_c = 2c\sqrt{k_p^2} = 2(600\ PSF)\sqrt{4.974} = \underline{2676.3^{\#}/Ft^2}$$
$$p_t = [GWT(\gamma') + (H-GWT)(\gamma)]k_p^2 = (10'(122.4-62.4) + (20-10)(110))\ 4.974$$
$$= \underline{8455.8^{\#}/Ft^2}$$
$$p_{H_2O} = (z1 + (H-GWT))\gamma_{H_2O} = (5.21' + 20' - 10')\ 62.4 = \underline{949.1^{\#}/Ft^2}$$

$$\Sigma p_r = 13636.1^{\#}/Ft^2$$

LEFT SIDE (ACTIVE)

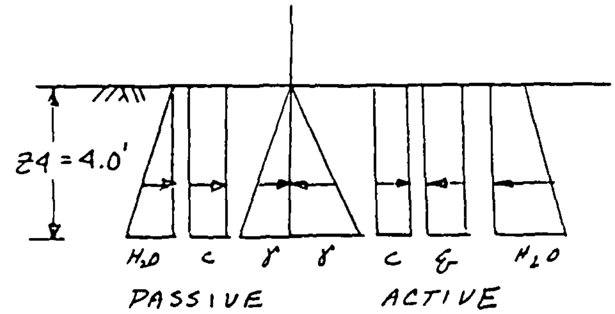
$$p_\gamma = -\gamma'(z1) k_a = (122.4-62.4)(5.21')(.3014) = -94.2^{\#}/Ft^2$$
$$p_c = +2c\sqrt{k_a} = 2(600)\sqrt{.3014} = 658.8^{\#}/Ft^2$$
$$p_{H_2O} = -\gamma_{H_2O}\ z1 = 62.4(5.21') = -325.1^{\#}/Ft^2$$

$$\Sigma p_L = 239.5^{\#}/Ft^2$$

$$PR = \Sigma p_r + \Sigma p_\ell$$
$$= 13636.1 + 239.5$$
$$= \underline{\underline{13875.6 \ \#/Ft^2}}$$

✓

COMPOSITE PRESSURE @ $z = z4 = 4.0'$



LEFT SIDE (PASSIVE)

$$p_\gamma = -\gamma'(z4)\,k_p = (122.4-62.4)(4.0')(4.974) = \underline{-1193.8 \ \#/Ft^2}$$

$$p_c = -2c\sqrt{k_p} = -2(600)\sqrt{4.974} = \underline{-2676.3 \ \#/Ft^2}$$

$$p_{H_2O} = -\gamma_{H_2O}\, z4 = 62.4 \cdot 4.0' = \underline{-249.6 \ \#/Ft^2}$$

$$\Sigma p_\ell = \underline{-4119.7 \ \#/Ft^2}$$

RIGHT SIDE (ACTIVE)

$$p_\gamma = \gamma'(z4)\,k_a = (122.4-62.4)(4.0')\,.3014 = \underline{72.34 \ \#/Ft^2}$$

$$p_c = -2c\sqrt{k_a} = -2(600)\sqrt{.3014} = \underline{-658.8 \ \#/Ft^2}$$

$$p_\varepsilon = [GWT(\gamma') + (H-GWT)(\gamma)]\,k_a$$
$$= [10'(60) + (20'-10')(110) = \underline{512.4 \ \#/Ft^2}$$

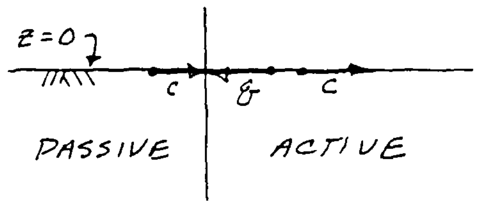
$$p_{H_2O} = (z4 + (H-GWT))\,\gamma_{H_2O} = (4.0' + 20' - 10')\,62.4 = \underline{873.6 \ \#/Ft^2}$$

$$\Sigma p_r = \underline{799.54 \ \#/Ft^2}$$

$P1 = \Sigma p_e + \Sigma p_r$

$= {}^{-}3320.2 \ ^{\#}/Ft^2$ ✓

COMPOSITE PRESSURE @ $z = 0$



LEFT SIDE (PASSIVE)

$p_c = -2c\sqrt{K_p} = {}^{-}2(600)\sqrt{4.974} = {}^{-}2676.3 \ ^{\#}/Ft^2$

RIGHT SIDE (ACTIVE)

$p_c = -2c\sqrt{K_a} = {}^{-}2(600)\sqrt{.3014} = {}^{-}658.8 \ ^{\#}/Ft^2$

$p_\gamma = [GWT(\gamma') + (H - GWT)\gamma]K_a =$

$= (10(122.4 - 62.4) + (20' - 10')(110)].3014 = 512.4 \ ^{\#}/Ft^2$

$p_{H_2O} = (H - GWT)\gamma_{H_2O} = (20' - 10')62.4 = 624 \ ^{\#}/Ft^2$

$\Sigma p_r = 477.6 \ ^{\#}/Ft^2$

$P2 = \Sigma p_e + \Sigma p_r$

$= {}^{-}2198.7 \ ^{\#}/Ft^2$ ✓

REFER TO FIGURE ($\frac{+}{\rightarrow}$)

CALCULATE Z5

$$\frac{X - X_1}{Y - Y_1} = \frac{X_2 - X_1}{Y_2 - Y_1} \qquad \begin{pmatrix} X = \text{PRESSURE} \\ Y = \text{DEPTH} \end{pmatrix}$$

$$\frac{0 - (^-3320.2)}{Z5 - 4.0'} = \frac{13875.6 - (^-3320.2)}{5.21' - 4.0'}$$

$$\underline{Z5 = 4.234'}$$

CALCULATE F7 - FØ

$F7 = P2\,(Z4) = ^-2198.7(4.0') = \underline{^-8794.8^{\#}}$

$F8 = \frac{1}{2}(P1 - P2)(Z4) = \frac{1}{2}(^-3320.2 - ^-2198.7)(4.0') = \underline{^-2243.0^{\#}}$

$F9 = \frac{1}{2}\,P1\,(Z5 - Z4) = \frac{1}{2}(^-3320.2)(4.234 - 4.0) = \underline{^-388.5^{\#}}$

$FØ = \frac{1}{2}\,PR\,(Z1 - Z5) = \frac{1}{2}(13875.6)(5.21 - 4.234) = \underline{6771.3^{\#}}$

$\Sigma F \xleftarrow{+}$

$\Sigma F = F1 + F2 + F3 + F4 + F5 + F7 + F8 + F9 + FØ$

$= 1657.7 + 3315.4 + 404.2 - 4392.0 + 3120$
$\quad - 8794.8 - 2243.0 - 388.5 + 6771.3$

$= \underline{\underline{-49.7^{\#} \simeq 0}}$

AD-A139 271 COMPUTER APPLICATIONS TO GEOTECHNICAL ENGINEERING(U) 2/3
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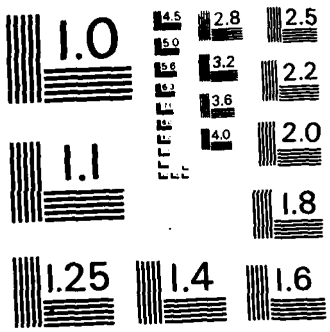


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVER ARMS (REFER TO FIGURE)

FORCE	LEVER ARM		
F1	$LA = \frac{1}{3}(10') + 10' + 4.23'$	$= 17.56'$	✓
F2	$LB = \frac{1}{2}(10') + 4.23'$	$= 9.23'$	✓
F3	$LC = \frac{1}{3}(10') + 4.23'$	$= 7.56'$	✓
F4	$LD = \frac{1}{2}(20') + 4.23'$	$= 14.23'$	✓
F5	$LE = \frac{1}{3}(10') + 4.23'$	$= 7.56'$	✓
F7	$LG = \frac{1}{2}(4') + (4.23' - 4')$	$= 2.23'$	✓
F8	$LH = \frac{1}{3}(4') + (4.23 - 4')$	$= 1.56'$	✓
F9	$LI = \frac{2}{3}(4.23 - 4)$	$= .153'$	✓
Fϕ	$LJ = \frac{2}{3}(5.21 - 4.23)$	$= -.653'$	✓ *

(* LJ IS NEGATIVE FOR ΣM +)

ΣM + @ 25

$$\Sigma M = F1(LA) + F2(LB) + F3(LC) + F4(LD) + F5(LE) + F7(LG) + F8(LH) + F9(LI) + F\phi(LJ)$$

$$= 1657.7(17.56) + 3315.4(9.23) + 904.2(7.56) - 9392.0(14.23) + 3120(7.56) - 8794.8(2.23) - 2243.0(1.56) - 388.5(.153) + 6771.3(-.653)$$

$$= \underline{42.56 \text{ Ft-\#}} \approx 0$$ ✓

REQUIRED DEPTH = 5.21' ✓

3.7.2 Problem #2

```
**********
**********
INPUT DATA
**********
**********


WET UNIT WEIGHT, SOIL #1 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #1 =122.4 PCF.

COHESION, SOIL #1 =0 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #1 =32 DEGREES.

FRICTION ANGLE, SOIL #1 =14 DEGREES.

WET UNIT WEIGHT, SOIL #2 =100 PCF.

SATURATED UNIT WEIGHT, SOIL #2 =112.4 PCF.

COHESION, SOIL #2 =1000 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #2 =28 DEGREES.

FRICTION ANGLE, SOIL #2 =15 DEGREES.

WALL HEIGHT =20 FEET.

 GROUND WATER DEPTH =23 FEET.

ACTIVE K, SOIL #1 =.28006464

PASSIVE K, SOIL #2 =4.48311107

ACTIVE K, SOIL #2 =.325042267

TOLERANCE =.05 PERCENT.

SAFETY FACTOR =1.
```

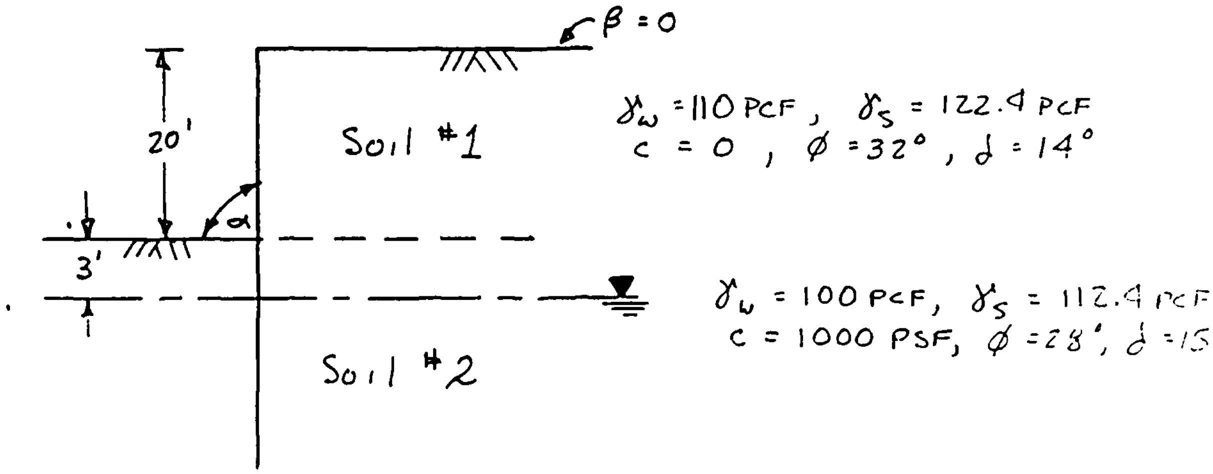
****
****
OUTPUT DATA
****
****

REQUIRED WALL PENETRATION =6.15 FEET.

****
SUPPLEMENTARY DATA
****

Z1 =6.15013255 FEET.
Z4 =3.67646922 FEET.
Z5 =4.32224836 FEET.
Z6 =0 FEET.
Z7 =0 FT.
P1 =-6047.88918 PSF.
P2 =-4659.82826 PSF.
P3 =-5907.2489 PSF.
P4 =0 PSF.
PR =17140.5978 PSF.
F1 =6161.42208#.
F2 =0#.
F3 =0#.
F4 =-13979.4848#.
F5 =-1871.13096#.
F6 =-47.5694097#.
F7 =-3996.07207#.
F8 =-1952.80034#.
F9 =15685.6354#.
F0 =0#.
FT =-4.57763672E-05#.

LA =10.988915FT.
LB =14.3222484FT.
LC =24.3222484FT.
LD =2.82224836FT.
LE =2.32224836FT.
LF =.871268881FT.
LG =.984013751FT.
LH =.430519429FT.
LI =-1.22015468FT.
LJ =0FT.
MT =-44.7207518FT-#.



k_a^1 = .28

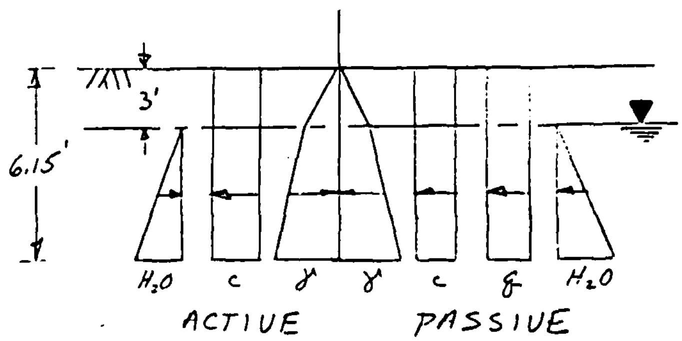
k_p^2 = 4.483

k_a^2 = .325

REFER TO FIGURE (±)

$F1 = \gamma_w' \, H^2/2 \; k_a' = 110\,\text{PCF} \cdot (20')^2/2 \cdot .28 = 6160^{\#}$

COMPOSITE PRESSURE @ z = 6.15'



RIGHT SIDE (PASSIVE)

$$p_\gamma = [(\gamma_w \cdot GWT) + (\gamma_s - \gamma_{H_2O})(z1 - GWT)]\, k_p$$
$$= [(100 \cdot 3') + (112.4 - 62.4)(6.15 - 3)]\, 4.483 = \underline{2050.97}\ ^{\#}/\text{Ft}^2$$

$p_c = 2c\sqrt{K_p} = 2(1000)\sqrt{4.483} = \underline{4234.62}$ #/Ft²

$p_\gamma = H\gamma_w k_p = 20'(110)(4.483) = \underline{9862.6}$ #/Ft²

$p_{H_2O} = \gamma_{H_2O}(z1 - GWT) = 62.4(6.15-3) = \underline{196.56}$ #/Ft²

$\Sigma p_r = \underline{16344.75}$ #/Ft²

LEFT SIDE (ACTIVE)

$p_\gamma = -[(\gamma_w \cdot GWT) + (\gamma_s - \gamma_{H_2O})(z1 - GWT)]k_a$
$= -[(100 \cdot 3) + (112.4 - 62.4)(6.15-3)] \cdot 325 = \underline{-148.69}$ #/Ft²

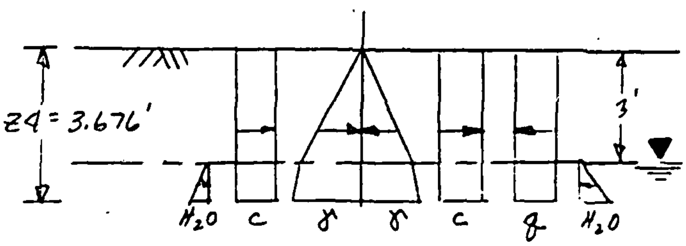
$p_c = 2c\sqrt{K_a} = 2(1000)\sqrt{.325} = \underline{1140.18}$ #/Ft²

$p_{H_2O} = -\gamma_{H_2O}(z1 - GWT) = -62.4(6.15-3) = \underline{-196.56}$ #/Ft²

$\Sigma p_e = \underline{794.93}$ #/Ft²

$PR = \Sigma p_e + \Sigma p_r$
$= \underline{17139.68}$ #/Ft² ✓

COMPOSITE PRESSURE @ $z = z4 = 3.676'$



LEFT SIDE (PASSIVE)

$p_\gamma = -[(\gamma_w \cdot GWT) + (\gamma_s - \gamma_{H_2O})(z - GWT)]K_p$
$= -[(100 \cdot 3) + (50)(3.676 - 3)] 4.483 = \underline{-1496.4?}$ #/Ft²

$p_c = -2c\sqrt{K_p} = -2(1000)\sqrt{4.483} = \underline{-4234.6}\ \#/Ft^2$

$p_{H_2O} = -\gamma_{H_2O}(z - GWT) = -62.4(3.676-3) = \underline{-42.18}\ \#/Ft^2$

$\Sigma p_\ell = \underline{-5773.2}\ \#/Ft^2$

RIGHT SIDE (ACTIVE)

$p_\gamma = [(\gamma_w \cdot GWT) + (\gamma_s - \gamma_{H_2O})(z - GWT)]K_a$
$= [(100 \cdot 3) + (50)(3.676 - 3)]\ .325 = \underline{108.48}\ \#/Ft^2$

$p_c = -2c\sqrt{K_a} = -2(1000)\sqrt{.325} = \underline{-1140.2}\ \#/Ft^2$

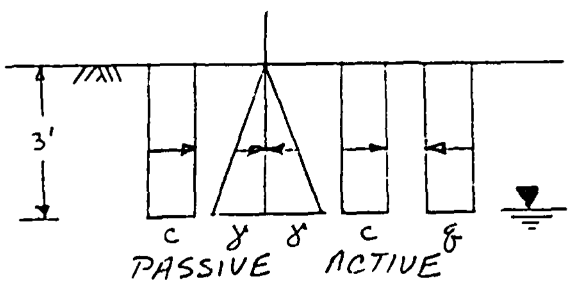
$p_q = \gamma H k_a = 110(20')\ .325 = \underline{715.0}\ \#/Ft^2$

$p_{H_2O} = \gamma_{H_2O}(z - GWT) = \underline{42.18}\ \#/Ft^2$

$\Sigma p_r = \underline{-274.54}\ \#/Ft^2$

$P1 = \Sigma p_r + \Sigma p_\ell$
$= \underline{\underline{-6047.74}}\ \#/Ft^2$ ✓

COMPOSITE PRESSURE @ z = GWT (3')



LEFT SIDE (PASSIVE)

$p_\gamma = -\gamma_w(GWT)k_p = -100(3')4.483 = \underline{-1344.9}\ \#/Ft^2$

$p_c = -2c\sqrt{k_p} = -2(1000)\sqrt{4.483} = \underline{-4234.6}\ \#/Ft^2$

$\Sigma p_\ell = \underline{-5579.5}\ \#/Ft^2$

RIGHT SIDE (ACTIVE)

$p_\gamma = \gamma_w\,(GWT)\,k_a = 100(3)\,.325 = \underline{97.5}\ \#/Ft^2$

$p_c = -2c\sqrt{k_a} = -2(1000)\sqrt{.375} = \underline{-1140.2}\ \#/Ft^2$

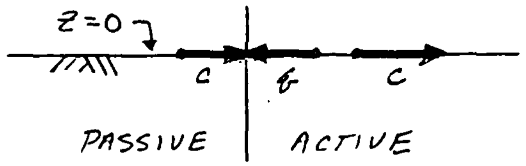
$p_\gamma = \gamma_w H\, k_a = 110(20')\,.325 = \underline{715.0}\ \#/Ft^2$

$\Sigma p_r = \underline{-327.67}\ \#/Ft^2$

$P3 = \Sigma p_r + \Sigma p_e$

$= \underline{\underline{-5907.2}}\ \#/Ft^2$ ✓

COMPOSITE PRESSURE @ $z = 0$



LEFT SIDE (PASSIVE)

$p_c = -2c\sqrt{k_p} = -2(1000)\sqrt{4.483} = \underline{-4234.6}\ \#/Ft^2$

RIGHT SIDE (ACTIVE)

$p_c = -2c\sqrt{k_a} = -2(1000)\sqrt{.325} = \underline{-1140.2}\ \#/Ft^2$

$p_\gamma = \gamma H\, k_a = 110(20')\,.325 = \underline{715.0}\ \#/Ft^2$

$\Sigma p_r = \underline{-425.2}\ \#/Ft^2$

$P2 = \Sigma p_e + \Sigma p_r$

$= \underline{\underline{-4659.8}}\ \#/Ft^2$ ✓

CALCULATE F4-F9 (SEE FIGURE) $Z5 = 4.321$

$F4 = P2\,(6WT) = {}^{-}4659.8\,(3') = \underline{-13979.4}\,\#$ ✓

$F5 = \tfrac{1}{2}(P3 - P2)(6WT) = \tfrac{1}{2}({}^{-}5907.2 - {}^{-}4659.8)(3) = \underline{-1871.1}\,\#$ ✓

$F6 = \tfrac{1}{2}(P1 - P3)(Z4 - 6WT) = \tfrac{1}{2}({}^{-}6047.4 - {}^{-}5907.2)(3.676 - 3) = \underline{{}^{-}47.4}\,\#$ ✓

$F7 = P3\,(Z4 - 6WT) = {}^{-}5907.2\,(3.676 - 3) = \underline{-3993.3}\,\#$ ✓

$F8 = \tfrac{1}{2}P1(Z5 - Z4) = \tfrac{1}{2}({}^{-}6047.4)(4.321 - 3.676) = \underline{-1950.3}\,\#$ ✓

$F9 = \tfrac{1}{2}PR(Z1 - Z5) = \tfrac{1}{2}(17139.68)(6.15 - 4.321) = \underline{15674.0}\,\#$ ✓

$\Sigma F \xleftarrow{+}$

$\Sigma F = F1 + F4 + F5 + F6 + F7 + F8 + F9$

$= 6160 - 13979.4 - 1871.1 - 47.4 - 3993.3 - 1950.3 + 15674$

$= \underline{-7.5} \approx 0$ ✓

LEVER ARM

FORCE	LEVER ARM	
F1	$LA = 4.321' + \tfrac{1}{3}(20') = 10.99'$	✓
F4	$LD = 4.321' - \tfrac{1}{2}(3') = 2.82'$	✓
F5	$LE = 4.321 - \tfrac{2}{3}(3') = 2.32'$	✓
F6	$LF = (4.321 - 3.676) + \tfrac{1}{3}(3.676 - 3) = .87'$	✓
F7	$LG = (4.321 - 3.676) + \tfrac{1}{2}(3.676 - 3) = .983'$	✓
F8	$LH = \tfrac{2}{3}(4.321 - 3.676) = .43'$	✓
F9	$LI = \tfrac{2}{3}(6.15 - 4.321) = -1.22'$	✓

ΣM ↶+ @ Z5

$$\Sigma M = F1(LA) + F4(LD) + F5(LE) + F6(LF) + F7(LG) + F8(LH) + F9(LI)$$

$$= 6160(10.99) - 13979.4(7.82) - 1871.1(2.32) - 47.4(.87) - 3993.3(.983) - 1950.3(.43) + 15674(-1.22)$$

$$= \underline{7.9 \text{ Ft-\#}} \approx 0$$

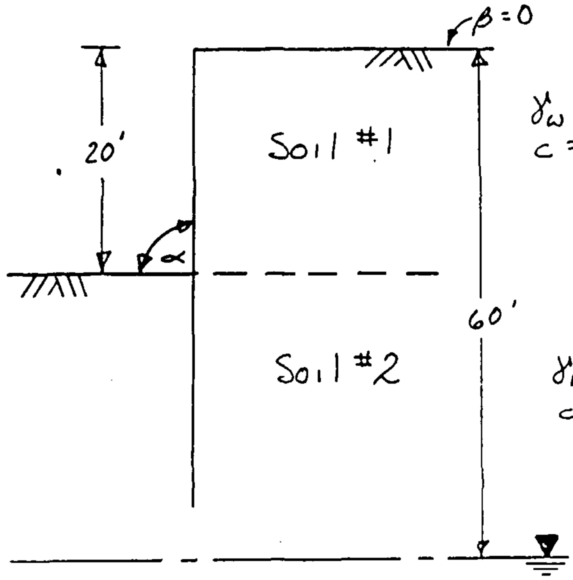
✓

<u>REQUIRED DEPTH = 6.15'</u>

3.7.3 Problem #3

```
**********
**********
INPUT DATA
**********
**********

WET UNIT WEIGHT, SOIL #1 =110 PCF.

SATURATED UNIT WEIGHT, SOIL #1 =122.4 PCF.

COHESION, SOIL #1 =0 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #1 =32 DEGREES.

FRICTION ANGLE, SOIL #1 =15 DEGREES.

WET UNIT WEIGHT, SOIL #2 =100 PCF.

SATURATED UNIT WEIGHT, SOIL #2 =112.4 PCF.

COHESION, SOIL #2 =1000 PSF.

ANGLE OF INTERNAL FRICTION, SOIL #2 =28 DEGREES.

FRICTION ANGLE, SOIL #2 =15 DEGREES.

WALL HEIGHT =20 FEET.

 GROUND WATER DEPTH =60 FEET.

ACTIVE K, SOIL #1 =.279048023

PASSIVE K, SOIL #2 =4.48311107

ACTIVE K, SOIL #2 =.325042267

TOLERANCE =.05 PERCENT.

SAFETY FACTOR =1.
```

```
***********
***********
OUTPUT DATA
***********
***********

REQUIRED WALL PENETRATION =6.1 FEET.

******************
SUPPLEMENTARY DATA
******************

Z1 =6.10066258 FEET.
Z4 =3.69574902 FEET.
Z5 =4.31743173 FEET.
Z6 =6.07054895 FEET.
Z7 =0 FT.
P1 =-6196.54613 PSF.
P2 =-4659.82826 PSF.
P3 =-21292.1035 PSF.
P4 =0 PSF.
PR =17774.4774 PSF.
F1 =6139.0565#.                  LA =10.9840984FT.
F2 =0#.                          LB =14.3174317FT.
F3 =0#.                          LC =24.3174317FT.
F4 =0#.                          LD =0FT.
F5 =0#.                          LE =0FT.
F6 =0#.                          LF =0FT.
F7 =-17221.5557#.                LG =2.46955722FT.
F8 =-2839.66178#.                LH =1.85359905FT.
F9 =-1926.1428#.                 LI =.414455141FT.
F0 =15848.3038#.                 LJ =-1.18884349FT.
FT =3.81469727E-06#.             MT =-.663588911FT-#.
```



$\gamma_w = 110$ PSF , $\gamma_s' = 122.4$ PSF
$c = 0$, $\phi = 32°$, $\delta = 15°$

$\gamma_w = 100$ PCF , $\gamma_s' = 112.4$ PCF
$c = 1000$ PSF, $\phi = 28°$, $\delta = 15°$

$k_a^1 = .279$

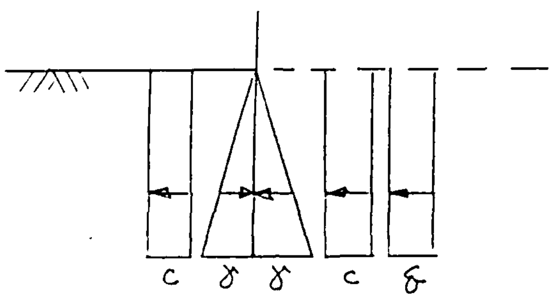
$k_p^2 = 4.483$ VERIFIED COMPUTER CALCULATION

$k_a^2 = .325$

REFER TO FIGURE

$F1 = \gamma' H^2/2 \; k_a^1 = 110\,\text{PCF}\,(20')^2/2\,(.279) = \underline{6138^{\#}}$ ✓

COMPOSITE PRESSURE @ $z1 = 6.1'$ (S.F.=1)



RIGHT SIDE (PASSIVE)

$p_\gamma = \gamma (z_1) k_p = 100 \text{ pcf } (6.1')(4.483) = \underline{2734.6} \ \#/ft^2$

$p_c = 2c\sqrt{k_p} = 2(1000)\sqrt{4.483} = \underline{4234.6} \ \#/ft^2$

$p_q' = \gamma_1 H k_p = 20'(110 \text{ pcf})(4.483) = \underline{9862.6} \ \#/ft^2$

$\Sigma p_r = \underline{16831.8} \ \#/ft^2$

LEFT SIDE (ACTIVE)

$p_\gamma = -\gamma (z_1) k_a = {}^-100 \text{ pcf } (6.1') .325 = \underline{{}^-198.25} \ \#/ft^2$

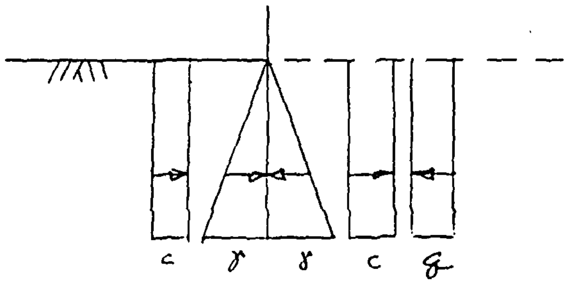
$p_c = 2c\sqrt{k_a} = 2(1000)\sqrt{.325} = \underline{1140.17} \ \#/ft^2$

$\Sigma p_\ell = \underline{941.92} \ \#/ft^2$

$PR = \Sigma p_\ell + \Sigma p_r$

$= \underline{\underline{17773.72}} \ \#/ft^2$

COMPOSITE PRESSURE @ $z = z_4 = 3.696'$



LEFT SIDE (PASSIVE)

$p_\gamma = -\gamma (z_4) k_p = {}^-100 (3.696) 4.483 = \underline{{}^-1656.9} \ \#/ft^2$

$p_c = -2c\sqrt{k_p} = -2(1000)\sqrt{4.483} = \underline{-4234.6} \ \#/ft^2$

$\Sigma p_\ell = \underline{-5891.5} \ \#/ft^2$

RIGHT SIDE (ACTIVE)

$p_\gamma' = \gamma(z4)\,k_a = 100\,(3.696)\,(.325) = \underline{120.12}\ \#/Ft^2$

$p_c = -2c\sqrt{k_a} = -2\,(1000)\,\sqrt{.325} = \underline{-1140.2}\ \#/Ft^2$

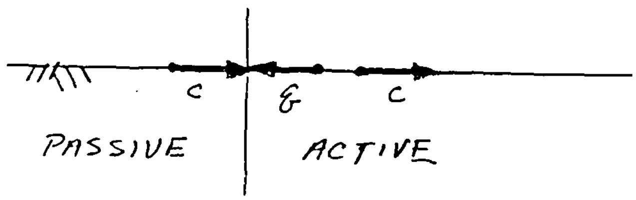
$p_G = \gamma H K_a = 110\,(20')\,.325 = \underline{715.0}\ \#/Ft^2$

$\Sigma p_r = \underline{-305}\ \#/Ft^2$

$P1 = \Sigma p_r + \Sigma p_L$

$= \underline{\underline{-6196.6}}\ \#/Ft^2$

COMPOSITE PRESSURE @ $z = 0$



LEFT SIDE (PASSIVE)

$p_c = -2c\sqrt{K_p} = -\underline{4234.6}\ \#/Ft^2$

RIGHT SIDE (ACTIVE)

$p_G = \gamma H k_a = \underline{715.0}\ \#/Ft^2$

$p_c = -2c\sqrt{k_a} = \underline{-1140.2}\ \#/Ft^2$

$P2 = \Sigma p_L \cdot \Sigma p_r$

$= \underline{\underline{-4659.8}}\ \#/Ft^2$

REFER TO FIGURE $\left(\overset{+}{\rightleftarrows} \right)$ $Z5 = 4.317'$

CALCULATE F7 - Fϕ

$F7 = P2(Z4) = {}^{-}4659.8\ \#/Ft^2 (3.696') = \underline{{}^{-}17222.6\ \#}$

$F8 = \tfrac{1}{2}(P1-P2)(Z4) = \tfrac{1}{2}(6196.6 - {}^{-}4659.8)(3.696) = \underline{{}^{-}2840.0\ \#}$

$F9 = \tfrac{1}{2}(P1)(Z5-Z4) = \tfrac{1}{2}({}^{-}6196.6)(4.317 - 3.696) = \underline{{}^{-}1929.0\ \#}$

$F\phi = \tfrac{1}{2} PR (Z1-Z5) = \tfrac{1}{2}(17773.72)(6.1 - 4.317) = \underline{15845.3\ \#}$

ΣF $\overset{+}{\leftarrow}$

$\Sigma F = F1 + F7 + F8 + F9 + F\phi$

$= 6138 - 17222.6 - 2840.0 - 1929.0 + 15845.3$

$= \underline{-3.3\ \#} \approx 0$ ✓

LEVER ARMS

FORCE	LEVER ARM	
F1	$LA = 4.317' + \tfrac{1}{3}(20') = 10.98'$	✓
F7	$LG = \tfrac{1}{2}(3.696) + (4.317 - 3.696) = 2.47'$	✓
F8	$LH = \tfrac{1}{3}(3.696) + (4.317 - 3.696) = 1.85'$	✓
F9	$LI = \tfrac{2}{3}(4.317 - 3.696) = .414'$	✓
Fϕ	$LJ = -\tfrac{2}{3}(6.1 - 4.317) = {}^{-}1.189'$	✓

ΣM $\circlearrowleft +$

$\Sigma M = F1(LA) + F7(LG) + F8(LH) + F9(LI) + F\phi(LJ)$

$= 6138(10.98) - 17222.6(2.47) - 2840(1.85) - 1924(.414) - 15845.3(1.189)$

$= \underline{-35.2\ Ft\text{-}\#} \approx 0$ ✓

REQUIRED DEPTH = 6.1'

3.8 References

1. Bowles, J. E., Foundation Analysis and Design, McGraw-Hill Co., New York, 1982.

2. NAVFAC (1982), "Design Manual: Foundations and Earth Structures," DM-7.2, Department of the Navy, Alexandria, Virginia, pp. 7.2-95.

3. Terzaghi, K., Theoretical Soil Mechanics, John Wiley & Sons, New York, 1943.

4. Winterkorn, H. F., and Fang, H., Foundation Engineering Handbook, Van Nostrand Reinhold Co., New York, 1975.

CHAPTER IV

SLOPE STABILITY

4.1 Problem Definition

The program, BISHOP1, calculates the stability of earth slopes. The Bishop method of slices is used (Bishop, 1955). The slope is assumed to fail in a well defined circular arc. The earth mass is assumed to remain in a solid state at the time of failure. See Figure 4.1 for the generalized geometry of the problem. A reservoir or pool may be specified.

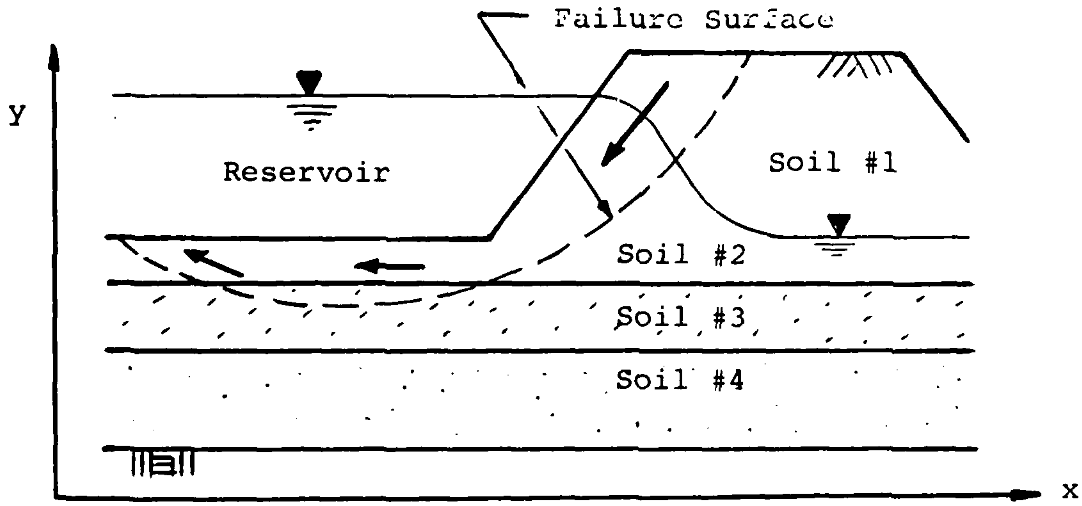


Figure 4.1. General Problem Definition.

4.2 Background Theory

4.2.1 General

A landslide is the failure of a soil mass beneath a slope [1]. A slide involves the downward and outward movement of the soil mass. Slides occur at various rates. Some slides are sudden and provide no warning; conversely, other slides fail slowly producing cracks and other visible signs of impending failure. The safety of the earth mass against failure is termed its stability [2]. The stability of earth masses must be considered whenever the possible failure of a slope may damage a structure or cause harm to individuals.

Slope failure occurs when the shear strength of the soil is exceeded by the shear stresses distributed over a finite continuous surface. Among the major factors which influence slope stability are: failure plane geometry, non-homogeneity of soil layers, tension cracks, dynamic loading or earthquakes, and seepage flow [4].

4.2.2 Limit Equilibrium Analysis

The limit equilibrium analysis of slope stability is composed of several methods varying in complexity and applicability to particular conditions. The ultimate solution of a limit equilibrium analysis is the determination of a factor of safety. "The factor of safety is that factor by which the shear strength parameters may be reduced in order to bring the slope into a state of limiting equilibrium

along a given slip surface" [5]. This definition implies a uniform state of stresses along a given failure plane.

Classes of analysis within the limit equilibrium analysis include the Culmann method (straight line failure plane), Bishop's method (circular arc failure plane), the logarithmic failure plane method, and the irregular failure plane method (Janbu, 1954). Each method introduces an additional degree of complexity; subsequently, the resulting factor of safety is hoped to reflect the actual conditions better than its predecessor [4].

4.2.3 Bishop's Method

The slice method, as originally proposed by Fellenius (1927), is the basis of Bishop's method of slope stability analysis. Bishop's method assumes a circular failure surface. Circles' centers and radii are varied until the minimum factor of safety is calculated. Figure 4.2 illustrates the safety factor contours created by iteratively solving the stability analysis. The circle center is the minimum factor of safety of the slope.

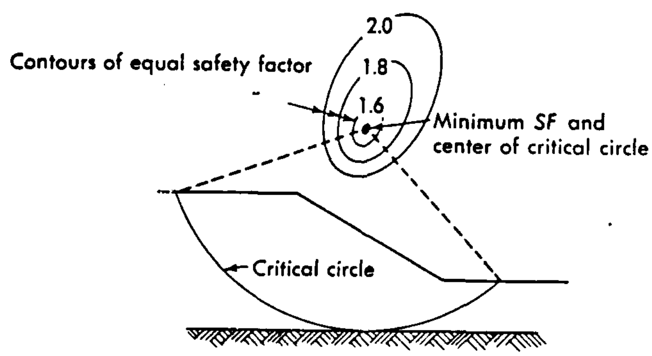


Figure 4.2. Slope Stability Safety Factor Contours [2].

For each slice, the forces are evaluated according to the limit equilibrium of the slice. Figure 4.3 illustrates the forces considered to act on a slice.

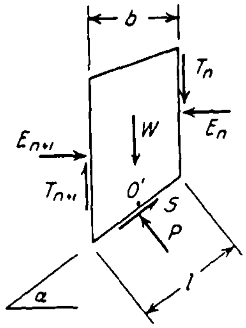


Figure 4.3. Forces Acting on a Single Slice [1].

where,

b = slice width

α = slice inclination

P = normal force on slice bottom

W = slice weight

S = shear force on slice bottom

E_n = normal force on slice side

T_n = shear force on slice side

The equilibrium of the entire soil mass is evaluated by summing the forces acting on all the slices. Because the factor of safety appears on both sides of the limiting

equilibrium equation, iterations are required for each failure surface. The equation is as follows:

$$F = \frac{\Sigma(Cb + P\tan\phi)\sec\alpha}{\dfrac{1 + \dfrac{\tan\phi\tan\alpha}{F}}{\Sigma W \sin\alpha}}$$

where,

ϕ = angle of internal friction

C = cohesion

α = slice inclination

F = factor of safety

The user can find the derivation of this equation in reference 5, p. 161.

Earthquake forces treated as equivalent static forces are added as additional driving forces. The force, F, is calculated by accelerating the slice mass.

$F = ma$

$m = \frac{W}{g}$

$a = k_{eq}$

therefore,

$F = k_{eq}W$

where,

F = earthquake force

m = slice mass

W = slice weight

g = acceleration of gravity

k_{eq} = seismic coefficient

The earthquake force may reduce the normal force acting on the bottom of the slice [3].

4.3 Program Use and Limitations

4.3.1 General

BISHOP1 was translated into Applesoft Basic Language by the author. The original slope stability program was programmed in TRS-80 Basic language and was presented in reference 3 by Cross. Since the author did not program the software, the programming rationale for selection of particular program flow paths is not presented. During translation of the program, all print and input statements were modified; additionally, the program was altered to calculate a rapid drawdown without repetitive data input.

The program is user oriented. All input is prompted by brief, concise statements and questions. As with any program, the user should be familiar with the associated theory, required input data, and the sequence of input. The user is urged to tabulate *and check* the input data prior to running the program.

4.3.2 Data Input

As depicted in Figure 4.4, the geometry of the physical conditions is specified by a series of point and line numbers. The user should graphically display the problem using an appropriate scale such that the entire problem is in the first quadrant. Points on the top soil line must be numbered

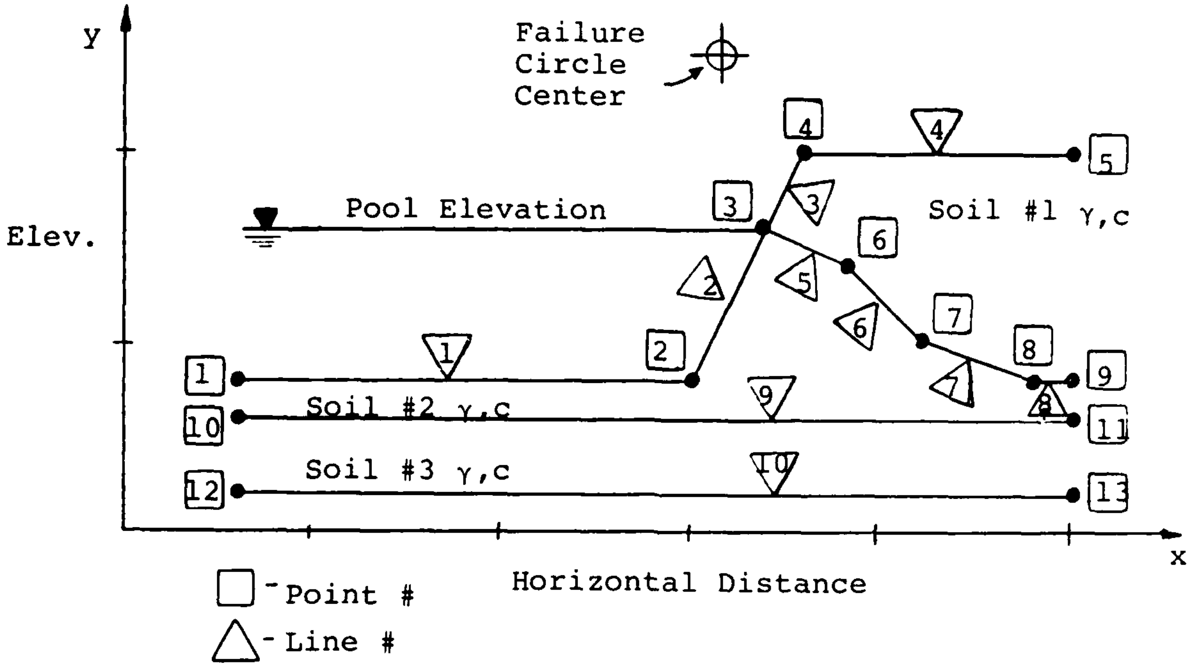


Figure 4.4. Input Parameters for Slope Stability Analysis.

from left to right. The user must insure that the extreme left points are outside of the specified failure circle; similarly, the extreme right points must be outside the failure circle. Below the top soil line, points may be numbered at random, but the interpretation of output data is simplified by maintaining a left-to-right numbering order. Point numbers are specified by their x and y coordinates.

Lines are specified by the left and right point numbers. Vertical lines are not permitted. If a vertical line is

required, the user may slope the line by an insignificant amount; i.e., .01. Interpretation of the output data is simplified by maintaining a consistent left-to-right numbering order, but it is not required.

Soil types are specified by number. While inputting line data, the user must specify which soil is beneath the particular line. Soil physical properties are input as the angle of internal friction, cohesion, the unit weight, and an indication if the soil is saturated (0 = yes, 1 = no). Saturation implies the soil is below the groundwater table; this is the method used to specify groundwater table location.

The failure circle is specified by inputting the x and y coordinates of the circle center and the radius.

The pool or reservoir is specified by the pool surface elevation and the extreme left and right x-coordinates of the line defining the pool water level. The piezometric surface within the soil mass is identified by indicating a saturated soil while inputting the soil data; therefore, the phreatic surface is a series of lines with a wet soil above and a saturated soil beneath.

Any units may be used but must be consistent; i.e., feet, pounds, and degrees.

The sequence of input is as follows:

a) problem heading

b) pool elevation

c) extreme left x-coordinate of pool

d) extreme right x-coordinate of pool

e) water unit weight

f) earthquake seismic coefficient, k_{eq}

g) total number of points to be specified for all lines (see Section 4.3.5, Limitations). Note that the pool water level does not have line points associated with it.

h) point #1, x-coordinate

i) point #1, y-coordinate

j) point #i, x-coordinate

k) point #i, y-coordinate

l) number of lines (see Section 4.3.5)

m) left point, line #1

n) right point, line #1

o) soil beneath line #1

p) left point, line #i

q) right point, line #i

r) soil beneath line #i

s) number of soil types (see Section 4.3.5)

t) unit weight, soil #1

u) cohesion, soil #1

v) phi angle, soil #1

w) is soil saturated, 0 = yes, 1 = no

x) unit weight, soil #i

y) cohesion, soil #i

z) phi angle, soil #i

aa) is soil saturated, 0 = yes, 1 = no

bb) minimum number of slices to be used (see Section 4.3.3)

cc) x-coordinate of circle center

dd) y-coordinate of circle center

ee) failure circle radius

ff) drawdown option (see Section 4.3.3)

See Section 4.5 for a printout of the above statements and associated input for an example problem. As previously mentioned, the user should create a table of input parameters prior to running BISHOP1. Example Problem #1 has approximately one hundred input variables.

4.3.3 Options

BISHOP1 can calculate a rapid drawdown condition without repetitive input of the problems physical geometry. This option is prompted by a question after the initial input of data and again following the output of calculated data. If the user desires to calculate the safety factor for only a drawdown condition, a pool elevation of 0 should be input. The rapid drawdown option sets the pool elevation equal to zero and does not affect the phreatic surface.

In most design studies, both the steady state and rapid drawdown conditions are analyzed. To analyze both cases, first calculate the steady state safety factor by specifying a pool elevation. At the completion of this analysis, the computer asks if a rapid drawdown analysis is desired. At

that time, specify a rapid drawdown condition and calculate the slope stability. This sequence provides the most information with the least required user input.

A minimum number of slices can be specified (the computer may use more slices in some instances). The original program automatically sets the minimum number of slices at 10 [3]. The program was modified to allow the user to specify a minimum number. The maximum number is set at 25 slices due to the memory constraints of the hardware. The author has successfully used 25 slices, but in approximately 50% of the cases, an "Out of Memory" error was encountered. The number of slices specified is contingent on the number of points, lines, and soil types input; the user must use trial and error to best suit the minimum number of slices to the physical geometry of the particular problem. The author never encountered an "Out of Memory" error when 10 slices were specified. Fewer than 10 slices should not be used for most problems.

The key advantage of BISHOP1 is the user option to specify various failure circles without re-entering physical geometry data. At the end of each run, the user is prompted to define another failure circle. After defining the new circle, the program repeats the stability analysis using the physical geometry data previously input. The rapid drawdown option is used concurrently with the above option. As depicted in Figure 3.2, the user can manually "search"

for the minimum factor of safety by establishing contours based on successive runs.

4.3.4 Output

Output of calculated data is composed of three general types. The first is automatically printed at the end of each run and consists of the calculated factor of safety, circle definition, and earthquake loading factor. The second section of output is at the option of the user. When specified, a "formal printout" of all input data will be printed. When successive runs are made while searching out the minimum factor of safety, the "formal printout" should not be specified until after the last run. The "formal printout" is used to document the output data, thus enabling the user to identify a particular series of circle definitions and factors of safety to a particular problem.

The third option is a list of variables calculated during a particular stability analysis. Each diagnostic list will be different for each circle definition or physical geometry. The diagnostic option creates a list of slices and the corresponding weights, inclinations, cohesions, widths, effective weights, phi angles, and lever arms (X) used in the stability analysis. Additionally, the factor of safety iterations are listed and the net force required to provide a factor of safety equal to one. See Section 4.5 for a printout of the diagnostic list.

4.3.5 Limitations

The number of points, lines, soil types, and number of slices are limited. To avoid program errors, the user must not specify more variables than allowed by Table 4.1.

Table 4.1. Input Limitations.

Parameter	Maximum
Points	20
Lines	20
Soil types	5
Slices	25*

*Refer to Section 4.3.3.

The physical geometry of the problem must be specified completely within the first quadrant. No negative values of x and y coordinates are allowed. No vertical lines may be specified. As previously discussed, offsetting the x-coordinate of a vertical line by an insignificant amount will suffice to avoid this limitation.

A slope must be specified to move up and out away from the coordinate origin as depicted in Figure 4.1. Erroneous slope stabilities were calculated when this rule was not followed. By rotating the scope geometry 180° such that the embankment sloped up and out away from the origin, a

correct factor of safety was obtained. This limitation was not mentioned by Cross in his presentation [3].

A limitation of BISHOP1 is the lack of a search routine which would yield a minimum factor of safety without user intervention. Main frame computing facilities have programs available to perform this task; for example, ICES LEASE I. Once again, this ability is dependent upon memory requirements beyond the capacity of most personal computers.

4.3.6 Warnings

In Section 4.3.2, the user was advised to ensure that the extreme left and right points were outside the failure circle. If the user ignored this, the warning, "Circle exceeds top line end points" will be printed. The user will then be prompted to input another failure circle. If the failure circle previously specified must be used, the point x-coordinates must be altered such that the failure circle is within the extreme left or right points. The user must restart the program to redefine the problem.

When the user defines a circle with a radius not large enough to intercept the slope the warning, "Circle does not intercept slope" will be printed. The user will be prompted to define a new failure circle. Input of physical geometry is not required. See Section 4.5 for an example of this warning.

The final warning advises the user that more than ten iterations are required to calculate the factor of safety.

No user intervention is required as the program will continue to iterate the factor of safety. If the warning continues to appear, the preset iteration tolerance may be changed by altering line 3860. The preset tolerance is .005. If the user is experiencing repetitive warnings, try changing .005 to .01 to avoid this problem. More than ten iterations were never required to calculate the factor of safety during verification of this program.

4.4 Program List

```
5  SPEED= 150
10  PRINT "**************************"
15  PRINT "**SIMPLIFIED BISHOP SLOPE**"
20  PRINT "**   STABILITY ANALYSIS  **"
25  PRINT "**************************"
27  PRINT : PRINT : PRINT : PRINT :
30  PRINT "  DANA K. EDDY, 578-80-8378"
35  PRINT "  GEORGIA INSTITUTE OF TECHNOLOGY"
40  PRINT "  DEPT. OF CIVIL ENGINEERING"
45  PRINT "  GEOTECHNICAL ENGINEERING DIV."
47  PRINT : PRINT : PRINT
50  PRINT "  PROGRAM DATE: JUNE 1983"
55  PRINT "  SYSTEM HARDWARE: APPLE II PLUS,64K"
60  PRINT "  SYSTEM SOFTWARE: DOS 3.3, APPLESOFT"
62  PRINT : PRINT : PRINT
65  PRINT "  THIS PROGRAM CALCULATES THE FACTOR OF SAFETY OF AN EARTH SLOP
   E AGAINST A CIRCULAR FAILURE.  THE SIMPLIFIED BISHOP SLOPE STABILITY
   ANALYSIS IS USED."
67  PRINT : PRINT : PRINT
70  SPEED= 255
140  DIM P(20,2),L(20,3),S2(5,4),A(50),F(50,14),Z(50,8)
155 PI = 3.14159
160 J6 = 0
170  REM  ***INPUT PROGRAM VARIABLES***
180  PRINT "PROBLEM HEADING"
190  INPUT H$
195  PRINT
200  PRINT "SUBMERGENCE ELEVATION (0 IF NO SUBMERGENCE)"
210  INPUT S0
215  PRINT
220  PRINT "FROM X-COORDINATE"
230  INPUT S6
235  PRINT
240  PRINT "TO X-COORDINATE"
250  INPUT S7
255  PRINT
260  PRINT "WATER UNIT WEIGHT"
270  INPUT W0
275  PRINT
280  PRINT "EARTHQUAKE LOADING FACTOR"
290  INPUT E1
295  PRINT : PRINT
300  PRINT "NUMBER OF POINTS"
310  INPUT P1
315  PRINT
320  FOR I = 1 TO P1
330  PRINT "POINT #"I
340  PRINT "X-COORDINATE"
350  INPUT P(I,1)
355  PRINT
```

```
360  PRINT "Y-C00RDINATE"
370  INPUT P(I,2)
375  PRINT
380  NEXT I
385  PRINT
390  PRINT "NUMBER OF LINES"
400  INPUT L1
405  PRINT
410  FOR I = 1 TO L1
420  PRINT "LINE #"I
425  PRINT
430  PRINT "LEFT POINT"
440  INPUT L(I,1)
445  PRINT
450  PRINT "RIGHT POINT"
460  INPUT L(I,2)
465  PRINT
470  PRINT "SOIL BENEATH LINE #"I
480  INPUT L(I,3)
485  PRINT
490  NEXT I
495  PRINT : PRINT
500  PRINT "NUMBER OF SOIL TYPES"
510  INPUT S1
515  PRINT
520  FOR I = 1 TO S1
530  PRINT "SOIL #"I
535  PRINT
540  PRINT "UNIT WEIGHT"
550  INPUT S2(I,1)
555  PRINT
560  PRINT "COHESION"
570  INPUT S2(I,2)
575  PRINT
580  PRINT "PHI ANGLE"
590  INPUT S2(I,3)
595  PRINT
600  PRINT "IS SOIL SATURATED, 0=YES, 1=NO ?"
610  INPUT S2(I,4)
615  PRINT
620  NEXT I
625  PRINT : PRINT
627  PRINT "SPECIFY THE MINIMUM NUMBER OF SLICES TO BE USED (MAX = 25)."
628  INPUT S9
629  PRINT : PRINT
630  REM
640 F9 = 0
650  PRINT "FAILURE CIRCLE DEFINITION"
655  PRINT : PRINT
660  PRINT "X-COORDINATE OF CENTER"
```

```
670  INPUT X
675  PRINT
680  PRINT "Y-COORDINATE OF CENTER"
690  INPUT Y
695 . PRINT
700  PRINT "CIRCLE RADIUS"
710  INPUT R
712  PRINT : PRINT
713  PRINT "FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PR
     EVIOUSLY SPECIFIED TYPE (1)"
714  INPUT ZZ: IF ZZ = 1 THEN 716
715 S0 = 0
716  PRINT : PRINT
720  REM  **CHECK, CIRCLE EXCEEDS TO LINE END POINTS**
730 U1 = P1
740  FOR I = 2 TO P1
750  IF P(I,1) < P(I - 1,1) AND U1 = P1 THEN 770
760  GOTO 780
770 U1 = I - 1
780  NEXT I
790 J1 = R * R - (P(1,2) - Y) ^ 2
800 J2 = R * R - (P(U1,2) - Y) ^ 2
810  IF J1 <  = 0 THEN 830
820.  IF J1 > 0 AND P(1,1) > X -  SQR (J1) THEN 860
830  IF J2 <  = 0 THEN 850
840  IF J2 > 0 AND P(U1,1) < X +  SQR (J2) THEN 860
850  GOTO 880
860  PRINT "* CIRCLE EXCEEDS TOP LINE END POINTS *"
870  GOTO 4380
880  REM  **DEFINE INTERSECTION OF CIRCLE WITH LINES**
890  FOR I = 1 TO L1
900 X1 = P(L(I,1),1)
910 Y1 = P(L(I,1),2)
920 X2 = P(L(I,2),1)
930 Y2 = P(L(I,2),2)
940  IF X2 = X1 THEN 960
950  GOTO 970
960 S = 9.99E + 10
970  IF X2 <  > X1 THEN 990
980  GOTO 1000
990 S = (Y2 - Y1) / (X2 - X1)
1000  IF  ABS (S) < 1.0E - 5 THEN 1150
1010 C1 = X1 - Y1 / S
1020 C2 = 1 / S ^ 2 + 1
1030 C3 = 2 * C1 / S - 2 * X / S - 2 * Y
1040 C4 = C1 ^ 2 - 2 * X * C1 + X ^ 2 + Y ^ 2 - R ^ 2
1050 C5 = C3 ^ 2 - 4 * C2 * C4
1060  IF C5 < 0 THEN 1080
1070  GOTO 1090
1080 Z(I,1) = 0
```

```
1090  IF C5 < 0 THEN 1630
1100 Q1 = ( - C3 +  SQR (C5)) / (2 * C2)
1110 Q2 = ( - C3 -  SQR (C5)) / (2 * C2)
1120 Q3 = Q1 / S + C1
1130 Q4 = Q2 / S + C1
1140  GOTO 1240
1150 C5 = R ^ 2 - (Y - Y1) ^ 2
1160  IF C5 < 0 THEN 1180
1170  GOTO 1190
1180 Z(I,1) = 0
1190  IF C5 < 0 THEN 1630
1200 Q3 = X +  SQR (C5)
1210 Q4 = X -  SQR (C5)
1220 Q1 = Y1
1230 Q2 = Y1
1240 J1 = 0
1250 J2 = 0
1260  IF  ABS (S) <  = 9.99E + 9 AND Q3 =  > X1 AND Q3 <  = X2 THEN 1280
1270  GOTO 1290
1280 J1 = 1
1290  IF  ABS (S) <  = 9.99E + 9 AND Q4 =  > X1 AND Q4 <  = X2 THEN 1310
1300  GOTO 1320
1310 J2 = 1
1320  IF S <  - 9.99E + 9 AND Q1 >  = Y2 AND Q1 <  = Y1 THEN 1340
1330  GOTO 1350
1340 J1 = 1
1350  IF S <  - 9.99E + 9 AND Q2 >  = Y2 AND Q2 <  = Y1 THEN 1370
1360  GOTO 1380
1370 J2 = 1
1380  IF S > 9.99E + 9 AND Q1 >  = Y1 AND Q1 <  = Y2 THEN 1400
1390  GOTO 1410
1400 J1 = 1
1410  IF S > 9.99E + 9 AND Q2 >  = Y1 AND Q2 <  - Y2 THEN 1430
1420  GOTO 1440
1430 J2 = 1
1440 Z(I,1) = J1 + J2
1450  IF J1 = 1 THEN 1470
1460  GOTO 1480
1470 Z(I,2) = Q3
1480  IF J1 = 1 THEN 1500
1490  GOTO 1510
1500 Z(I,3) = Q1
1510  IF J1 = 0 AND J2 = 1 THEN 1530
1520  GOTO 1540
1530 Z(I,2) = Q4
1540  IF J1 = 0 AND J2 = 1 THEN 1560
1550  GOTO 1570
1560 Z(I,3) = Q2
1570  IF J1 = 1 AND J2 = 1 THEN 1590
1580  GOTO 1600
```

```
1590 Z(I,4) = Q4
1600  IF J1 = 1 AND J2 = 1 THEN 1620
1610  GOTO 1630
1620 Z(I,5) = Q2
1630  NEXT I
1640 X4 = 0
1650 X5 = 9.99E + 20
1660 I1 = 1
1670  FOR I = 1 TO L1
1680  IF Z(I,1) =  > 1 THEN 1700
1690  GOTO 1710
1700 A(I1) = Z(I,2)
1710  IF Z(I,1) =  > 1 THEN 1730
1720  GOTO 1740
1730 I1 = I1 + 1
1740  IF Z(I,1) = 2 THEN 1760
1750  GOTO 1770
1760 A(I1) = Z(I,4)
1770  IF Z(I,1) = 2 THEN 1790
1780  GOTO 1800
1790 I1 = I1 + 1
1800  NEXT I
1810  IF I1 = 1 THEN 1830
1820  GOTO 1840
1830  PRINT "CIRCLE DOES NOT INTERCEPT SLOPE"
1840  IF I1 = 1 THEN 4380
1850  REM  **SET UP OF SLICE ARRAY**
1860  FOR I = 1 TO I1 - 1
1870  IF A(I) > X4 THEN 1890
1880  GOTO 1900
1890 X4 = A(I)
1900  IF A(I) < X5 THEN 1920
1910  GOTO 1930
1920 X5 = A(I)
1930  NEXT I
1940  FOR I = 1 TO P1
1950  IF P(I,1) < X4 AND P(I,1) > X5 THEN 1970
1960  GOTO 1980
1970 A(I1) = P(I,1)
1980  IF P(I,1) < X4 AND P(I,1) > X5 THEN 2000
1990  GOTO 2010
2000 I1 = I1 + 1
2010  NEXT I
2020 I1 = I1 - 1
2030  FOR I = 1 TO I1
2040  FOR J = 1 TO I1 - 1
2050  IF A(J + 1) > A(J) THEN 2090
2060 J1 = A(J + 1)
2070 A(J + 1) = A(J)
2080 A(J) = J1
```

```
2090  NEXT J
2100  NEXT I
2110 U1 = 0
2120  FOR I = 1 TO I1 - 1
2130  IF A(I) < A(I + 1) THEN 2150
2140  GOTO 2190
2150 U1 = U1 + 1
2160  IF A(I) < A(I + 1) THEN 2180
2170  GOTO 2190
2180 A(U1) = A(I)
2190  NEXT I
2200 U1 = U1 + 1
2210 A(U1) = A(I1)
2220 I1 = U1
2230  REM  **DEFINE SLICE BOUNDARIES**
2240 Q1 = A(I1) - A(1)
2250 Q2 = Q1 / S9
2260 U1 = I1
2270  FOR I = 1 TO U1 - 1
2280 Q3 = A(I + 1) - A(I)
2290 Q4 =  INT (Q3 / Q2) + 1
2300 C1 = Q3 / Q4
2310 C2 = A(I)
2320  FOR J = 1 TO Q4
2330  IF J < Q4 THEN 2350
2340  GOTO 2360
2350 I1 = I1 + 1
2360  IF J < Q4 THEN 2380
2370  GOTO 2390
2380 A(I1) = C2 + C1
2390  IF J < Q4 THEN 2410
2400  GOTO 2420
2410 C2 = C2 + C1
2420  NEXT J
2430  NEXT I
2440  FOR I = 1 TO I1
2450  FOR J = 1 TO I1 - 1
2460  IF A(J + 1) > A(J) THEN 2500
2470 J1 = A(J + 1)
2480 A(J + 1) = A(J)
2490 A(J) = J1
2500  NEXT J
2510  NEXT I
2520  REM  **DEFINE SOIL PARAMETERS FOR EACH SLICE**
2530 F1 = I1 - 1
2540  FOR I = 1 TO F1
2550 F(I,4) = A(I + 1) - A(I)
2560 X6 = F(I,4)
2570 F(I,7) = (A(I + 1) + A(I)) / 2
2580 X3 = F(I,7)
```

```
2590 Y1 = Y -  SQR (R ^ 2 - (A(I) - X) ^ 2)
2600 Y2 = Y -  SQR (R ^ 2 - (A(I + 1) - X) ^ 2)
2610 A5 =  ATN ( ABS (Y2 - Y1) / F(I,4))
2620  IF Y2 < Y1 THEN 2640
2630  GOTO 2650
2640 A5 =  - A5
2650 F(I,2) = A5
2660  IF A5 = 0 THEN 2680
2670  GOTO 2690
2680 F(I,2) = 1.0E - 5
2690 Y3 = Y -  SQR (R ^ 2 - (X3 - X) ^ 2)
2700 I4 = 0
2710  FOR J = 1 TO L1
2720 L5 = L(J,1)
2730 L6 = L(J,2)
2740  IF P(L5,2) <  = Y3 AND P(L6,2) <  = Y3 THEN 2840
2750  IF P(L5,1) < X3 AND P(L6,1) < X3 THEN 2840
2760  IF P(L5,1) > X3 AND P(L6,1) > X3 THEN 2840
2770 Y6 = P(L5,2) + (P(L5,2) - P(L6,2)) / (P(L5,1) - P(L6,1)) * (X3 - P(L5
     ,1))
2780  IF Y6 <  = Y3 THEN 2840
2790 I4 = I4 + 1
2800 Z(I4,1) = Y6
2810 Z(I4,2) = L(J,3)
2820 W = 0
2830 E = 0
2840  NEXT J
2850  IF I4 = 1 THEN 2970
2860  FOR J = 1 TO I4
2870  FOR J1 = 1 TO I4 - 1
2880  IF Z(J1,1) =  > Z(J1 + 1,1) THEN 2950
2890 L5 = Z(J1,1)
2900 L6 = Z(J1,2)
2910 Z(J1,1) = Z(J1 + 1,1)
2920 Z(J1,2) = Z(J1 + 1,2)
2930 Z(J1 + 1,1) = L5
2940 Z(J1 + 1,2) = L6
2950  NEXT J1
2960  NEXT J
2970 I4 = I4 + 1
2980 Z(I4,1) = Y3
2990  FOR J1 = 1 TO I4 - 1
3000  IF I = 1 AND J1 = 1 AND X3 =  > S6 THEN 3020
3010  GOTO 3030
3020 I6 = S0 - Y1
3030  IF I = F1 AND J1 = 1 AND X3 =  > S6 AND X3 <  = S7 THEN 3050
3040  GOTO 3060
3050 J6 = S0 - Y2
3060 W = W + (Z(J1,1) - Z(J1 + 1,1)) * X6 * S2(Z(J1,2),1)
3070  IF Z(J1,1) < S0 AND X3 =  > S6 AND X3 <  = S7 THEN 3090
```

```
3080  GOTO 3100
3090 W = W + (S0 - Z(J1,1)) * X6 * W0
3100  IF S2(Z(J1,2),4) > 0.95 THEN 3120
3110  GOTO 3130
3120 E4 = S2(Z(J1,2),1)
3130  IF S2(Z(J1,2),4) < 0.95 THEN 3150
3140  GOTO 3160
3150 E4 = S2(Z(J1,2),1) - W0
3160 E = E + (Z(J1,1) - Z(J1 + 1,1)) * X6 * E4
3170  NEXT J1
3180 F(I,1) = W
3190 F(I,5) = E
3200 F(I,3) = S2(Z(I4 - 1,2),2)
3210 F(I,6) = 2 * PI * (S2(Z(I4 - 1,2),3) / 360)
3220  NEXT I
3230  IF F9 = 0 THEN 3360
3235 L$ =  CHR$ (4): PRINT L$;"PR#1"
3240  PRINT "SLICE   WEIGHT    INCLINATION  COHESION   WIDTH     EFF WEIGH
     T  PHI       X"
3241  PRINT
3280 O = 360 / (2 * PI)
3290  FOR I = 1 TO F1
3300  POKE 36,3: PRINT I;: POKE 36,7: PRINT F(I,1);: POKE 36,19: PRINT F(I
     ,2) * O;: POKE 36,34: PRINT F(I,3);: POKE 36,41: PRINT F(I,4);: POKE
     36,53: PRINT F(I,5);: POKE 36,65: PRINT F(I,6) * O;: POKE 36,69: PRINT
     F(I,7)
3340  NEXT I
3350  PRINT L$;"PR#0"
3360 D = 0
3370  FOR I = 1 TO F1
3380 D = D + F(I,1) *  SIN ( ABS (F(I,2))) * (F(I,2) /  ABS (F(I,2)))
3390 D = D + E1 * F(I,1) *  COS ( ABS (F(I,2)))
3400  NEXT I
3410  IF I6 > 0 THEN 3430
3420  GOTO 3440
3430 I7 = W0 * I6 * I6 * (R - I6 / 3) / (2 * R)
3440  IF I6 > 0 THEN 3460
3450  GOTO 3470
3460 D = D -  SGN (D) * I7
3470  IF I6 > 0 AND F9 = 1 THEN 3485
3480  GOTO 3510
3485 L$ =  CHR$ (4): PRINT L$;"PR#1"
3487  PRINT : PRINT
3490  PRINT "DRIVING FORCE COUNTER BALANCE OF "I7"#."
3495  PRINT : PRINT
3500  PRINT L$;"PR#0"
3510  IF J6 > 0 THEN 3530
3520  GOTO 3540
3530 I7 = W0 * J6 * J6 * (R - J6 / 3) / (2 * R)
3540  IF J6 > 0 THEN 3560
```

```
3550  GOTO 3570
3560 D = D +  SGN (D) * 17
3570  IF J6 > 0 AND F9 = 1 THEN 3585
3580  GOTO 3610
3585 L$ =  CHR$ (4): PRINT L$;"PR#1"
3587  PRINT : PRINT
3590  PRINT "DRIVING FORCE INCREASE OF "I7"#."
3595  PRINT : PRINT
3600  PRINT L$;"PR#0"
3610  REM  **ITERATIVE SOLUTION FOR FACTOR OF SAFETY**
3620 F0 = 1
3630 R4 = 0
3640 I6 = 0
3650  FOR I = 1 TO F1
3660 R1 = F(I,3) * F(I,4) + F(I,5) *  TAN (F(I,6))
3670 R2 = 1 /  COS ( ABS (F(I,2)))
3680 R3 = 1 +  TAN (F(I,6)) *  TAN (F(I,2)) / F0
3690 R4 = R4 + R1 * (R2 / R3)
3700  NEXT I
3710 F2 = R4 / D
3720 I6 = I6 + 1
3730  IF F9 = 1 THEN 3750
3740  GOTO 3820
3750  IF I6 = 1 THEN 3765
3760  GOTO 3775
3765 L$ =  CHR$ (4): PRINT L$;"PR#1"
3770  PRINT "ITERATION","INITIAL","CALCULATED"
3775 L$ =  CHR$ (4): PRINT L$;"PR#1"
3780  PRINT  TAB( 5)I6,F0,F2
3800  PRINT L$;"PR#0"
3820  IF I6 > 10 THEN 3840
3830  GOTO 3850
3840  PRINT "WILL NOT CLOSE"
3850  IF I6 > 10 THEN 3970
3860  IF  ABS ( ABS (F0) -  ABS (F2)) < 0.005 THEN 3910
3870 F0 =  ABS (F2)
3880 R4 = 0
3890  GOTO 3650
3895  PRINT : PRINT
3910 L$ =  CHR$ (4): PRINT L$;"PR            #1": PRINT : PRINT
3915  PRINT H$
3916  PRINT "**********************************"
3920  PRINT "FACTOR OF SAFETY = "F2;"  AT X ="X;"  Y ="Y;"  RADIUS ="R
3935  PRINT
3940  PRINT "EARTHQUAKE LOADING FACTOR ="E1
3955  PRINT : PRINT
3960  PRINT L$;"PR#0"
3965  HOME
3970  PRINT "DO YOU WANT A FORMAL PRINTOUT (Y OR N)?"
3980  INPUT A$
```

```
3985  PRINT : PRINT
3990  IF A$ = "N" THEN 4320
4005 L$ =  CHR$ (4): PRINT L$;"PR#1"
4007  PRINT H$
4008  PRINT : PRINT
4010  PRINT "WATER UNIT WEIGHT ="W0;"  EARTHQUAKE LOADING FACTOR ="E1
4020  PRINT "SUBMERGENCE ELEV ="S0;"  FROM X="S6;"  TO X="S7
4030  PRINT
4040  PRINT "POINT","X-COORDINATE","Y-COORDINATE"
4050  FOR I = 1 TO P1
4060  PRINT I,P(I,1),P(I,2)
4070  NEXT I
4080  PRINT : PRINT
4090  PRINT "LINE";"  LEFT PT";"  RIGHT PT";"  SOIL"
4100  FOR I = 1 TO L1
4110  POKE 36,2: PRINT I;: POKE 36,10: PRINT L(I,1);: POKE 36,19: PRINT L(
     I,2);: POKE 36,27: PRINT L(I,3)
4120  NEXT I
4130  PRINT : PRINT
4140  PRINT "SOIL";"  UNIT WEIGHT";"  COHESION";"  PHI";"  SAT'D"
4150  FOR I = 1 TO S1
4160  POKE 36,2: PRINT I;: POKE 36,10: PRINT S2(I,1);: POKE 36,21: PRINT S
     2(I,2);: POKE 36,30: PRINT S2(I,3);: POKE 36,37: PRINT S2(I,4)
4170  NEXT I
4180  PRINT : PRINT
4190  PRINT "CIRCLE: X="X;"  Y="Y;"  RADIUS ="R;"  FACTOR OF SAFETY ="F2
4200  PRINT : PRINT
4210  PRINT L$;"PR#0"
4215  HOME
4320  PRINT "DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?"
4330  INPUT A$
4332  PRINT : PRINT
4340  IF A$ = "Y" THEN 4360
4350  GOTO 4370
4360 F9 = 1
4370  IF A$ = "Y" THEN 720
4380  PRINT "DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?"
4390  INPUT A$
4391  PRINT : PRINT
4400  IF A$ = "Y" THEN 630
4410  PRINT "BYE-BYE"
```

4.5 Program Verification

4.5.1 Problem #1

```
***************************
**SIMPLIFIED BISHOP SLOPE**
**   STABILITY ANALYSIS  **
***************************


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  GEOTECHNICAL ENGINEERING DIV.


  PROGRAM DATE: JUNE 1983
  SYSTEM HARDWARE: APPLE II PLUS,64K
  SYSTEM SOFTWARE: DOS 3.3, APPLESOFT


  THIS PROGRAM CALCULATES THE FACTOR OF SAFETY OF AN EARTH SLOPE AGAINST A CIRCU
LAR FAILURE.  THE SIMPLIFIED BISHOP SLOPE STABILITY ANALYSIS IS USED.


PROBLEM HEADING
?AN EXAMPLE PROBLEM

SUBMERGENCE ELEVATION (0 IF NO SUBMERGENCE)
?1040

FROM X-COORDINATE
?0

TO X-COORDINATE
?132

WATER UNIT WEIGHT
?62.4

EARTHQUAKE LOADING FACTOR
?0


NUMBER OF POINTS
?13

POINT #1
X-COORDINATE
?0

Y-COORDINATE
?1020
```

```
POINT #2
X-COORDINATE
?100

Y-C00RDINATE
?1020

POINT #3
X-COORDINATE
?132

Y-C00RDINATE
?1040

POINT #4
X-COORDINATE
?162.5

Y-C00RDINATE
?1045

POINT #5
X-COORDINATE
?172.5

Y-C00RDINATE
?1045

POINT #6
X-COORDINATE
?235

Y-C00RDINATE
?1020

POINT #7
X-COORDINATE
?0

Y-C00RDINATE
?1000

POINT #8
X-COORDINATE
?300

Y-C00RDINATE
?1000
```

```
POINT #9
X-COORDINATE
?138

Y-C00RDINATE
?1035

POINT #10
X-COORDINATE
?150

Y-C00RDINATE
?1030

POINT #11
X-COORDINATE
?161

Y-C00RDINATE
?1027.5

POINT #12
X-COORDINATE
?168

Y-C00RDINATE
?1025

POINT #13
X-COORDINATE
?171

Y-C00RDINATE
?1020


NUMBER OF LINES
?13

LINE #1

LEFT POINT
?1

RIGHT POINT
?2

SOIL BENEATH LINE #1
?3
```

LINE #2

LEFT POINT
?2

RIGHT POINT
?3

SOIL BENEATH LINE #2
?2

LINE #3

LEFT POINT
?3

RIGHT POINT
?4

SOIL BENEATH LINE #3
?1

LINE #4

LEFT POINT
?4

RIGHT POINT
?5

SOIL BENEATH LINE #4
?1

LINE #5

LEFT POINT
?5

RIGHT POINT
?6

SOIL BENEATH LINE #5
?1

LINE #6

LEFT POINT
?3

RIGHT POINT
?9

SOIL BENEATH LINE #6
?2

LINE #7

LEFT POINT
?9

RIGHT POINT
?10

SOIL BENEATH LINE #7
?2

LINE #8

LEFT POINT
?10

RIGHT POINT
?11

SOIL BENEATH LINE #8
?2

LINE #9

LEFT POINT
?11

RIGHT POINT
?12

SOIL BENEATH LINE #9
?2

LINE #10

LEFT POINT
?12

RIGHT POINT
?13

SOIL BENEATH LINE #10
?2

LINE #11

LEFT POINT
?2

RIGHT POINT
?13

SOIL BENEATH LINE #11
?3

```
LINE #12

LEFT POINT
?13

RIGHT POINT
?6

SOIL BENEATH LINE #12
?3

LINE #13

LEFT POINT
?7

RIGHT POINT
?8

SOIL BENEATH LINE #13
?4


NUMBER OF SOIL TYPES
?4

SOIL #1

UNIT WEIGHT
?115

COHESION
?200

PHI ANGLE
?26

IS SOIL SATURATED, 0=YES, 1=NO ?
?1

SOIL #2

UNIT WEIGHT
?117

COHESION
?200

PHI ANGLE
?26

IS SOIL SATURATED, 0=YES, 1=NO ?
?0
```

```
SOIL #3

UNIT WEIGHT
?120

COHESION
?100

PHI ANGLE
?28

IS SOIL SATURATED, 0=YES, 1=NO ?
?0

SOIL #4

UNIT WEIGHT
?150

COHESION
?10000

PHI ANGLE
?45

IS SOIL SATURATED, 0=YES, 1=NO ?
?0


SPECIFY THE MINIMUM NUMBER OF SLICES TO BE USED (MAX = 25).
?10


FAILURE CIRCLE DEFINITION


X-COORDINATE OF CENTER
?108.7

Y-COORDINATE OF CENTER
?1100.8

CIRCLE RADIUS
?81.0

FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PREVIOUSLY SPECIFIED,
 TYPE (1)
?1
```

```
AN EXAMPLE PROBLEM
*********************************
FACTOR OF SAFETY = 2.64016612  AT X =108.7  Y =1100.8  RADIUS =81

EARTHQUAKE LOADING FACTOR =0


DO YOU WANT A FORMAL PRINTOUT (Y OR N)?
?Y


AN EXAMPLE PROBLEM


WATER UNIT WEIGHT =62.4  EARTHQUAKE LOADING FACTOR =0
SUBMERGENCE ELEV =1040  FROM X=0  TO X=132

POINT              X-COORDINATE    Y-COORDINATE
1                  0               1020
2                  100             1020
3                  132             1040
4                  162.5           1045
5                  172.5           1045
6                  235             1020
7                  0               1000
8                  300             1000
9                  138             1035
10                 150             1030
11                 161             1027.5
12                 168             1025
13                 171             1020


LINE   LEFT PT   RIGHT PT   SOIL
  1       1          2        3
  2       2          3        2
  3       3          4        1
  4       4          5        1
  5       5          6        1
  6       3          9        2
  7       9         10        2
  8      10         11        2
  9      11         12        2
 10      12         13        2
 11       2         13        3
 12      13          6        3
 13       7          8        4
```

SOIL	UNIT WEIGHT	COHESION	PHI	SAT'D
1	115	200	26	1
2	117	200	26	0
3	120	100	28	0
4	150	10000	45	0

CIRCLE: X=108.7 Y=1100.8 RADIUS =81 FACTOR OF SAFETY =2.64016612

DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
?Y

SLICE	WEIGHT	INCLINATION	COHESION	WIDTH	EFF WEIGHT	PHI	X
1	3419.83601	-4.96581439	200	2.64388013	137.423009	26	101.689478
2	15437.8547	-2.01358368	100	5.68858236	1185.89153	28	105.855709
3	16542.1386	2.01358368	100	5.68858236	2290.17546	28	111.544291
4	10617.9847	6.11577104	200	5.87047255	3387.01816	26	117.323819
5	11212.2684	10.3152172	200	5.87047255	4291.56704	26	123.194291
6	11499.2192	14.5718242	200	5.87047255	5052.69402	26	129.064764
7	11408.9623	18.9619938	200	6	6425.16599	26	135
8	9484.07119	23.3014683	200	5.43929673	6948.87283	26	140.719648
9	8372.38118	27.5671964	200	5.43929673	7483.64569	26	146.158945
10	1556.34339	30.1967314	200	1.12140656	1556.34339	26	149.439297
11	6689.7098	32.9750275	200	5.5	6689.7098	26	152.75
12	4794.2082	37.7555341	200	5.5	4794.2082	26	158.25
13	912.06297	40.9187278	200	1.5	912.06297	26	161.75
14	1399.49512	44.0393237	200	4.91422302	1399.49512	26	164.957112

DRIVING FORCE COUNTER BALANCE OF 11202.7845#.

ITERATION	INITIAL	CALCULATED
1	1	2.3702899
2	2.3702899	2.61883446
3	2.61883446	2.63872113
4	2.63872113	2.64016612

```
AN EXAMPLE PROBLEM
**********************************
FACTOR OF SAFETY = 2.64016612  AT X =108.7  Y =1100.8  RADIUS =81

EARTHQUAKE LOADING FACTOR =0


DO YOU WANT A FORMAL PRINTOUT (Y OR N)?
?N


DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
?N


DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?
?Y


FAILURE CIRCLE DEFINITION


X-COORDINATE OF CENTER
?108.7

Y-COORDINATE OF CENTER
?1100.8

CIRCLE RADIUS
?81.0


FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PREVIOUSLY SPECIFIED
 TYPE (1)
?0



AN EXAMPLE PROBLEM
**********************************
FACTOR OF SAFETY = 1.45417058  AT X =108.7  Y =1100.8  RADIUS =81

EARTHQUAKE LOADING FACTOR =0


DO YOU WANT A FORMAL PRINTOUT (Y OR N)?
?Y
```

AN EXAMPLE PROBLEM

WATER UNIT WEIGHT =62.4   EARTHQUAKE LOADING FACTOR =0
SUBMERGENCE ELEV =0   FROM X=0   TO X=132

POINT	X-COORDINATE	Y-COORDINATE
1	0	1020
2	100	1020
3	132	1040
4	162.5	1045
5	172.5	1045
6	235	1020
7	0	1000
8	300	1000
9	138	1035
10	150	1030
11	161	1027.5
12	168	1025
13	171	1020

LINE	LEFT PT	RIGHT PT	SOIL
1	1	2	3
2	2	3	2
3	3	4	1
4	4	5	1
5	5	6	1
6	3	9	2
7	9	10	2
8	10	11	2
9	11	12	2
10	12	13	2
11	2	13	3
12	13	6	3
13	7	8	4

SOIL	UNIT WEIGHT	COHESION	PHI	SAT'D
1	115	200	26	1
2	117	200	26	0
3	120	100	28	0
4	150	10000	45	0

CIRCLE: X=108.7   Y=1100.8   RADIUS =81   FACTOR OF SAFETY =1.45417058

```
DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
?Y
```

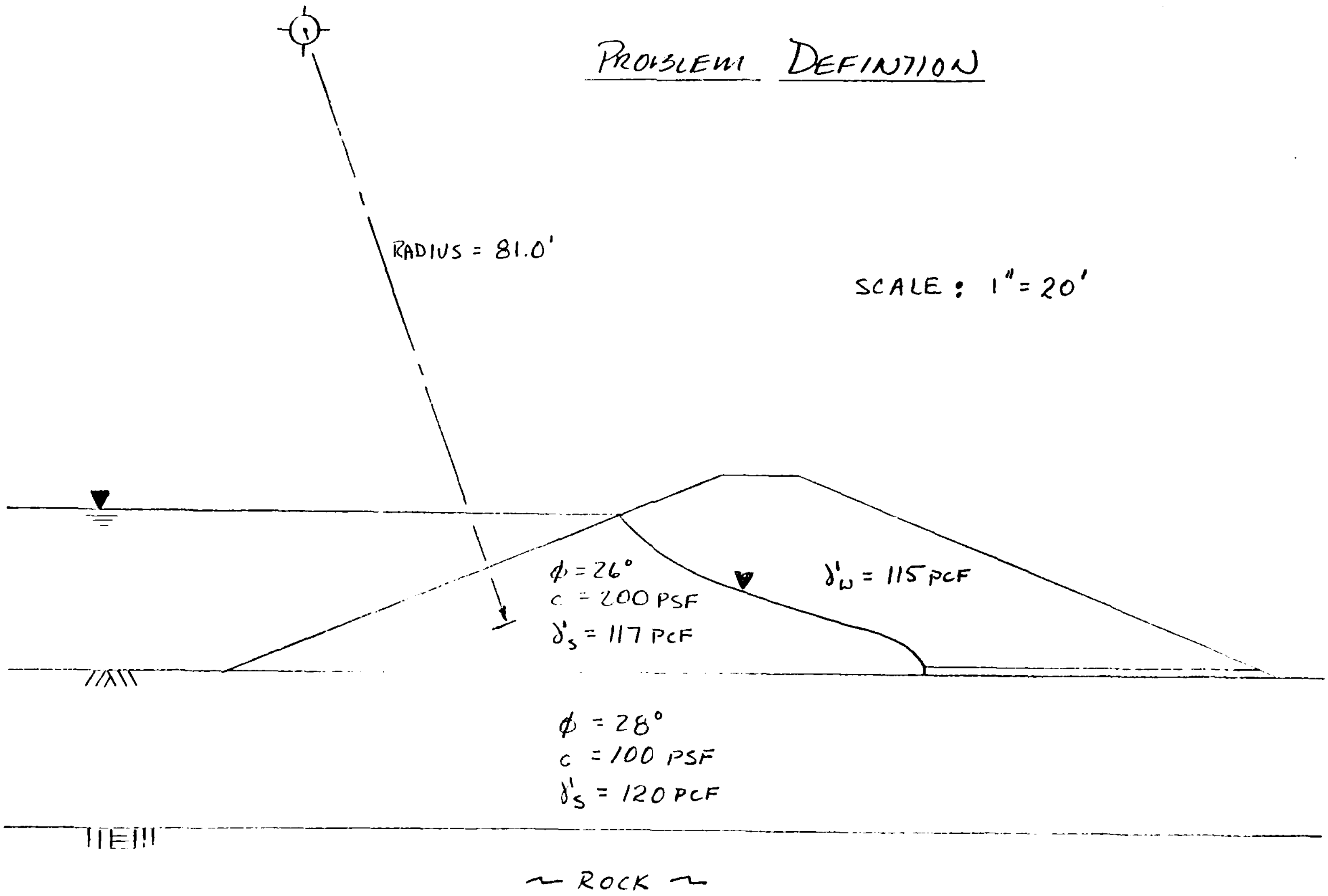
SLICE	WEIGHT	INCLINATION	COHESION	WIDTH	EFF WEIGHT	PHI	X
1	294.477875	-4.96581439	200	2.64388013	137.423009	26	101.689478
2	2538.26968	-2.01358368	100	5.68858236	1185.89153	28	105.855709
3	4904.59238	2.01358368	100	5.68858236	2290.17546	28	111.544291
4	7257.89607	6.11577104	200	5.87047255	3387.01816	26	117.323819
5	9196.21509	10.3152172	200	5.87047255	4291.56704	26	123.194291
6	10827.2015	14.5718242	200	5.87047255	5052.69402	26	129.064764
7	11408.9623	18.9619938	200	6	6425.16599	26	135
8	9484.07119	23.3014683	200	5.43929673	6948.87283	26	140.719648
9	8372.38118	27.5671964	200	5.43929673	7483.64569	26	146.158945
10	1556.34339	30.1967314	200	1.12140656	1556.34339	26	149.439297
11	6689.7098	32.9750275	200	5.5	6689.7098	26	152.75
12	4794.2082	37.7555341	200	5.5	4794.2082	26	158.25
13	912.06297	40.9187278	200	1.5	912.06297	26	161.75
14	1399.49512	44.0393237	200	4.91422302	1399.49512	26	164.957112

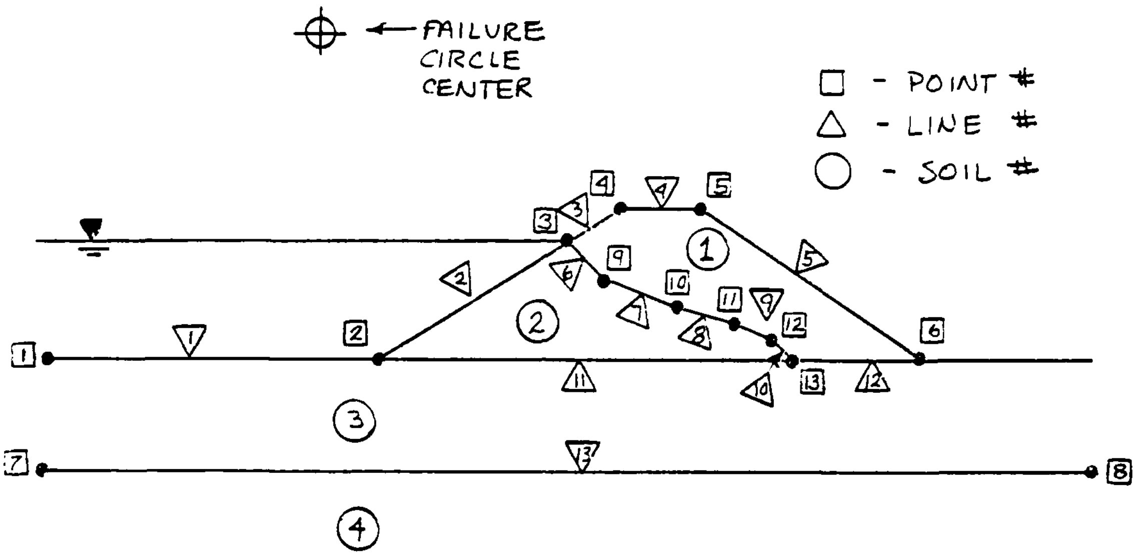
ITERATION	INITIAL	CALCULATED
1	1	1.38086936
2	1.38086936	1.44516603
3	1.44516603	1.45320706
4	1.45320706	1.45417058

```
AN EXAMPLE PROBLEM
*********************************
FACTOR OF SAFETY = 1.45417058  AT X =108.7  Y =1100.8  RADIUS =81

EARTHQUAKE LOADING FACTOR =0


DO YOU WANT A FORMAL PRINTOUT (Y OR N)?
?N


DO YOU WANT A DIAGNOSTIC RUN (Y OR N)?
?N
```

```
DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?
?Y

FAILURE CIRCLE DEFINITION

X-COORDINATE OF CENTER
?108.7

Y-COORDINATE OF CENTER
?1100.8

CIRCLE RADIUS
?40

FOR A RAPID DRAWDOWN TYPE (0), FOR SUBMERGENCE ELEVATION AS PREVIOUSLY SPECIFIED
 TYPE (1)
?1

CIRCLE DOES NOT INTERCEPT SLOPE
DO YOU WANT TO DEFINE ANOTHER FAILURE CIRCLE (Y OR N)?
?N

BYE-BYE
```

PROBLEM DEFINITION





POINT	X (Ft)	Y (Ft)
1	0	1020
2	100	1020
3	132	1040
4	162.5	1045
5	172.5	1045
6	235	1020
7	0	1000
8	300	1000
9	138	1035
10	150	1030
11	161	1027.5
12	168	1025
13	171	1020

LINE	LEFT PT	RIGHT PT	SOIL BENEATH
1	1	2	3
2	2	3	2
3	3	4	1
4	4	5	1
5	5	6	1
6	3	9	2
7	9	10	2
8	10	11	2
9	11	12	2
10	12	13	2
11	2	13	3
12	13	6	3
13	7	8	4

Soil	γ (PCF)	c (PSF)	ϕ	SATURATED (1=NO)
1	115	200	26	1
2	117	200	26	0
3	120	100	28	0
4 (ROCK)	150	10,000	45	0

FAILURE CIRCLE CENTER

X = 108.7' Y = 1100.8' RADIUS = 81'

FOR FULL POOL : ELEVATION = 1040'
FROM X = 0' → X = 132'

OCS CYBER 730
GTICES LEASE I SF = 2.72

Δ = 2.9%

BISHOP 1 SF = 2.64

FOR RAPID DRAWDOWN :

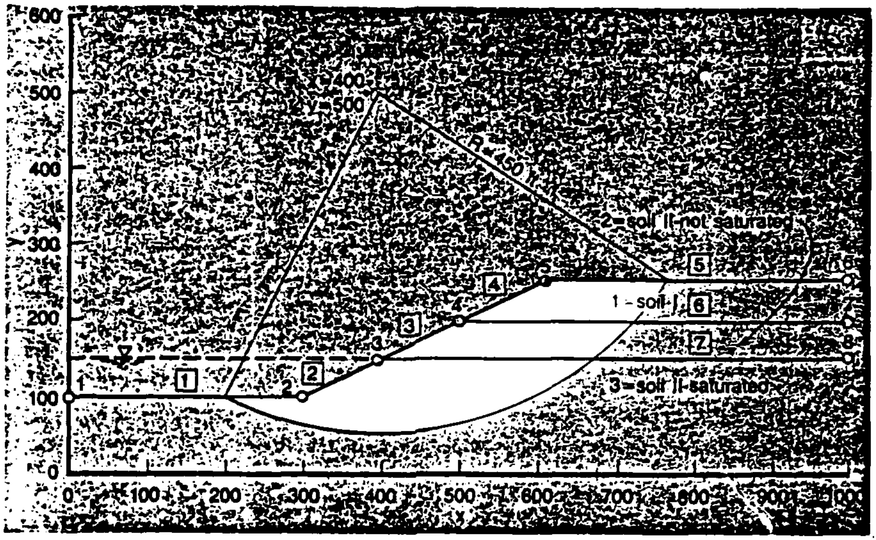
OCS CYBER 730
GTICES LEASE I SF = 1.42

Δ = 2.1%

BISHOP 1 SF = 1.45

4.5.2 Problem #2

Example Problem Presented by Cross [3].



Point	X	Y
1	0	100
2	300	100
3	400	150
4	500	200
5	600	250
6	1000	250
7	1000	200
8	1000	150

Line	Left	Right	Soil
1	1	2	3
2	2	3	3
3	3	4	2
4	4	5	1
5	5	6	1
6	4	7	2
7	3	8	3

Soil	α	Cohesion	Phi	Saturated
1	127	2000	20	No
2	130	1000	33	No
3	130	1000	33	Yes

```
FACTOR OF SAFETY=  1.96  AT X=  400 Y=  500 R=  450
EARTHQUAKE=  0.05

DO YOU WISH A FORMAL PRINTOUT (Y OR N)Y

SAMPLE SLOPE STABILITY PROBLEM

WATER UNIT WEIGHT= 62.40  EARTHQUAKE=0.05

SUBMERGENCE AT 150.00  FROM    0.0  TO  400.0

 POINT    X-ORD      Y-ORD
   1       0.00     100.00
   2     300.00     100.00
   3     400.00     150.00
   4     500.00     200.00
   5     600.00     250.00
   6    1000.00     250.00
   7    1000.00     200.00
   8    1000.00     150.00

     LINE    LEFT    RIGHT   SOIL
       1       1       2       3
       2       2       3       3
       3       3       4       2
       4       4       5       1
       5       5       6       1
       6       4       7       2
       7       3       8       3

SOIL      UNIT WEIGHT       COHESION    PHI     SATURATED
 1            127             2000       20         1
 2            130             1000       33         1
 3            130             1000       33         0

CIRCLE   X-ORD    Y-ORD    RADIUS  FACTOR OF SAFETY
         400.0    500.0    450.0        1.96
```

```
DO YOU WISH A DIAGNOSTIC RUN (Y OR N)Y
SLICE  WEIGHT    INCLINATION  COHESION  WIDTH  EFF WEIGTH      PHI     X
  1   252536.4     -23.6        1000     53.1    45205.8      33.0  220.38
  2   385318.3     -16.4        1000     53.1   114252.4      33.0  273.46
  3   482338.9      -9.6        1000     50.0   189976.2      33.0  325.00
  4   603232.6      -3.2        1000     50.0   293401.0      33.0  375.00
  5   726732.6       3.2        1000     50.0   416901.0      33.0  425.00
  6   852838.9       9.6        1000     50.0   560476.2      33.0  475.00
  7   939262.7      16.2        1000     50.0   682516.6      33.0  525.00
  8   982882.6      22.9        1000     50.0   781399.0      33.0  575.00
  9   759268.3      29.4        1000     41.4   650306.4      33.0  620.71
 10   617175.8      35.7        1000     41.4   576418.3      33.0  662.13
 11   518439.1      43.6        1000     52.6   518439.1      33.0  709.13
 12   131972.9      52.2        2000     38.8   131972.9      20.0  754.79

DRIVING FORCE COUNTER BALANCE OF      75111.11

ITERATION          INITIAL           CALCULATED
    1               1.0000              1.8106
    2               1.8106              1.9435
    3               1.9435              1.9570
    4               1.9570              1.9583

FACTOR OF SAFETY=  1.96  AT X=  400 Y=  500 R=  450
EARTHQUAKE=  0.05
```

Example Problem Calculated by BISHOP1.

(BISHOP1 is the slope stability program presented by Cross [3] translated into Applesoft)

```
SAMPLE SLOPE STABILITY PROBLEM
*********************************
FACTOR OF SAFETY = 1.95830517  AT X =400  Y =500  RADIUS =450

EARTHQUAKE LOADING FACTOR =.05


SAMPLE SLOPE STABILITY PROBLEM


WATER UNIT WEIGHT =62.4  EARTHQUAKE LOADING FACTOR =.05
SUBMERGENCE ELEV =150  FROM X=0  TO X=400

POINT              X-COORDINATE    Y-COORDINATE
1                  0               100
2                  300             100
3                  400             150
4                  500             200
5                  600             250
6                  1000            250
7                  1000            200
8                  1000            150


LINE  LEFT PT  RIGHT PT  SOIL
  1      1        2        3
  2      2        3        3
  3      3        4        2
  4      4        5        1
  5      5        6        1
  6      4        7        2
  7      3        8        3


SOIL  UNIT WEIGHT  COHESION  PHI  SAT'D
  1      127         2000     20    1
  2      130         1000     33    1
  3      130         1000     33    0

CIRCLE: X=400  Y=500  RADIUS =450  FACTOR OF SAFETY =1.95830517
```

SLICE	WEIGHT	INCLINATION	COHESION	WIDTH	EFF WEIGHT	PHI	X
1	252536.452	-23.5767355	1000	53.0776408	45205.7908	33	220.383539
2	385318.321	-16.363501	1000	53.0776407	114252.363	33	273.46118
3	482338.898	-9.60948742	1000	50	189976.227	33	325
4	603232.626	-3.18968777	1000	50	293400.965	33	375
5	726732.626	3.18968777	1000	50	416900.965	33	425
6	852838.898	9.60948742	1000	50	560476.227	33	475
7	939262.679	16.1554181	1000	50	682516.593	33	525
8	982882.646	22.9295296	1000	50	781398.976	33	575
9	759268.279	29.4164975	1000	41.4213565	650306.432	33	620.710678
10	617175.754	35.6938236	1000	41.4213562	576418.317	33	662.132035
11	518439.062	43.5661001	1000	52.5674844	518439.062	33	709.126455
12	131972.89	52.2203924	2000	38.7555423	131972.89	30	754.787968

DRIVING FORCE COUNTER BALANCE OF 75111.1116#.

ITERATION	INITIAL	CALCULATED
1	1	1.81060871
2	1.81060871	1.94350336
3	1.94350336	1.95701339
4	1.95701339	1.95830517

SAMPLE SLOPE STABILITY PROBLEM
****
FACTOR OF SAFETY = 1.95830517 AT X =400 Y =500 RADIUS =450

EARTHQUAKE LOADING FACTOR =.05

Results

Method	Factor of Safety
Cross [3]	1.96
BISHOP 1	1.958

4.6 References

1. Terzaghi, K., and Peck, R. B., Soil Mechanics in Engineering Practice, John Wiley & Sons, New York, 1967.

2. Sowers, G. B., and Sowers, G. F., Introductory Soil Mechanics and Foundations, MacMillan Publishing Co., Inc., 1970.

3. Cross, J. P., "Slope Stability Program," Civil Engineering, ASCE, October, 1982, pp. 71-74.

4. Winterkorn, H. F., and Fang, H., "Foundation Engineering Handbook," Van Nostrand Reinhold Co., New York, 1975.

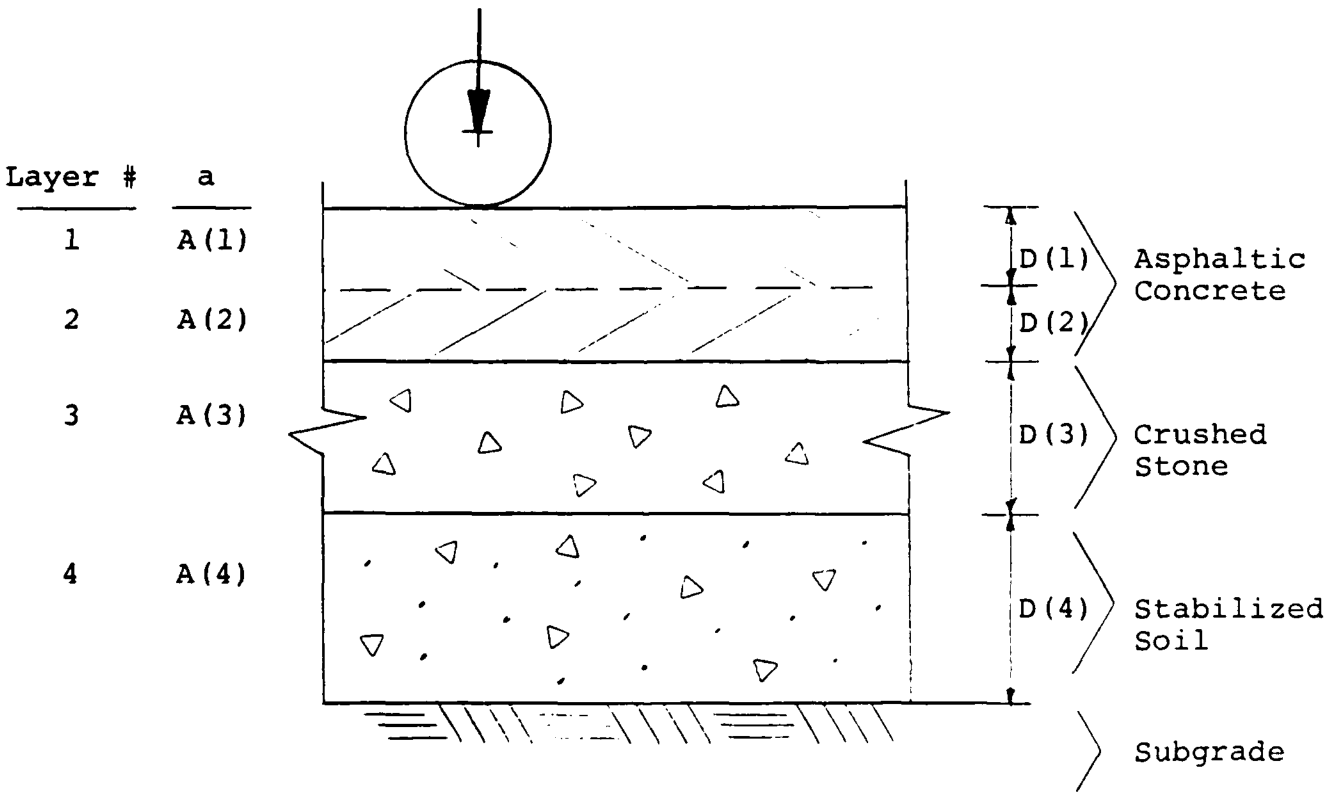
5. Schuster, R. L, and Krizek, R. J., "Landslides, Analysis and Control," Special Report 176, Transportation Research Board, Washington, D.C., 1978, pp. 155-164.

CHAPTER V

FLEXIBLE PAVEMENT DESIGN (AASHTO)

5.1 Problem Definition

AASHTO 1 is a computer program for the design of flexible pavements. AASHTO 1 is based on the design equations developed from the AASHO Road Test performed in 1958 by the American Association of State Highway Officials [1]. (See Figure 5.1.)



a - structural coefficient

D(i) - layer thickness

Figure 5.1. General Problem Definition.

AASHTO 1 is composed of two basic programs. The first program calculates the required thickness of a layer given the required design parameters and the characteristics of the other layers. The second program calculates the number of equivalent 18 kip wheel loads the pavement can endure over a projected 20-year service life. Both programs calculate the structural number.

5.2 Background Theory

5.2.1 General

The AASHO Road Test was performed in Illinois from 1958 through 1960. The test consisted of several pavement types constructed in a race track configuration. The pavements were subjected to various wheel loads and durations. So much data was collected that it took two years to produce the results and recommendations extrapolated from the test. The scope of the test was to produce a standardized design based on the useful service of a pavement versus theoretical structural design criteria. Rigid and flexible pavements were considered. This report deals only with flexible pavement design.

5.2.2 Flexible Pavement Construction

A flexible pavement consists of structural layers. The capacity of a layer to distribute load decreases from the top layer down to the subgrade. In general, a flexible pavement consists of a bituminous surface course, a base, and a subbase which in turn rests upon a soil subgrade.

The surface course is usually made of asphaltic concrete and is capable of distributing a wheel load to the base with a minimum amount of distortion or consolidation. By distributing the constant pressure of a wheel load such that the pressure is reduced at some finite depth, the base can be made up of a material which is less structurally capable than the surface course. This rationale applies to the subbase as well as the subgrade soil. From the AASHO Road Test, minimum thicknesses for flexible pavement layers were established as follows [1]:

Surface Course	2 inches
Base Course	4 inches
Subbase Course	4 inches

In many cases a subbase course is not used and the base course rests directly on the subgrade soil.

5.2.3 AASHTO Design Considerations

The principal factors of the AASHTO pavement design are [2]:

a) magnitude, method of application, and number of wheel loads

b) function of pavement and base in transmitting the load to the subgrade

c) measurement of the subgrades ability to support the transmitted load

5.2.3.1 Equivalent 18-kip Loads

The AASHTO design considers the number of equivalent 18-kip wheel loads (E-18's) applied to a pavement over a particular service life. Several methods of estimating this quantity have been established by various transportation and highway organizations. Methods range from traffic counters with load meters to extrapolating historic data. In many cases, organizations will expend more funds on collecting this data than can be rationalized for its intended purpose. Historic data will usually suffice as a means of projecting anticipated wheel loads. This is especially true when new interstates are being constructed as other factors will influence usage such as route direction, load limitations, city connections, and other regional limitations. Large amounts of data exist for equating given loads and load configurations to 18-kip single axle loads. Service organizations must adapt a method of calculating E-18's best suited for their region.

5.2.3.2 Soil Support

In the AASHO Road Test, a soil support value of 3 was established to represent the subgrade soil used which was an A-6 soil [2]. Crushed stone with a California Bearing Ratio (CBR) of 200 was assigned a soil support value of 10.

The soil support value of various soils have been established by different service organizations. Figure 5.2 and Tables 5.1 through 5.4 represent a selected group of soil

Table 5.1. Maximum Recommended Soil Support Values [6].

Classification	Description	Upper Soil Support Value
A-1a	Largely gravel but can include sand and fines	6.5
A-1b	Gravelly sand or graded sand; may include fines	6
A-2-4	Sands, gravels with low plasticity silt fines	5
2-2-4	Micaceous silty sands	2.5 - 3.0
A-2-5	Sands, gravels with plastic silt fines	4
A-2-6	Sands, gravels with clay fines	4.0 - 5.0
A-2-7	Sands, gravels with highly plastic clay fines	4.0
A-3	Fine sands	4.5
A-4	Low compressibility silts	4.0
A-5	High compressibility silts, micaceous silts and micaceous sandy silts	2.5 - 3.5
A-6	Low to medium compressibility clays	3.5 - 4.5
A-7	High compressibility clays, silty clays and high volume change clays	3-4

Table 5.2. Soil Support Values [2].

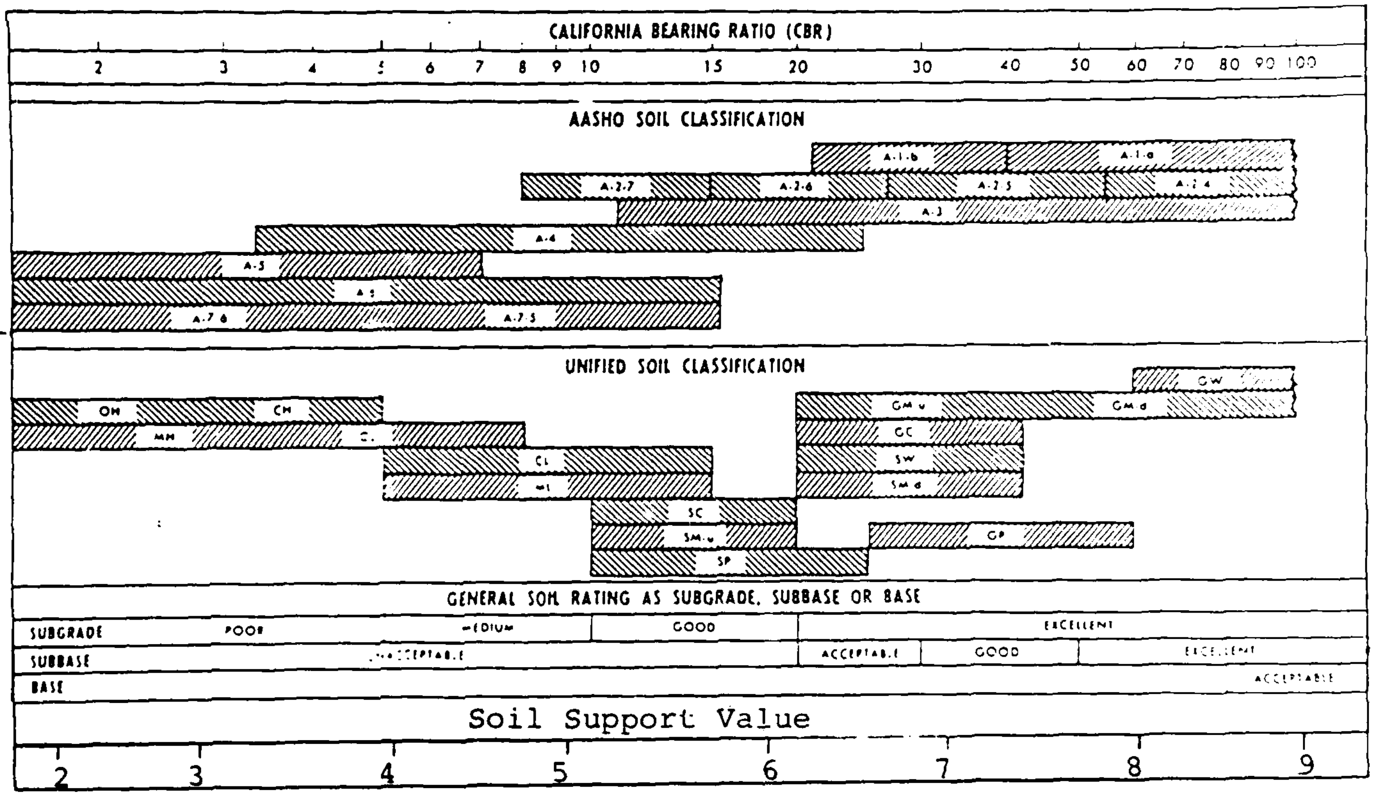


Table 5.3 Summary of Laboratory Test Results Repeatability Study, State of Utah [1].

Soil Type	Soil Support	Dynamic CBR	Static CBR	AASHTO 3-Point CBR	R-Value (240psi)*	R-Value (300psi)*
A-7-6	3.9	4.9	7.2	1.9	8.4	12.0
A-4-5	4.9	8.9	8.0	5.2	10.5	14.8
A-2-4	7.2	38.9	42.6	9.9	68.2	72.2
A-1-9	8.4	78.0	116.5	17.2	75.5	77.2

* Exudation pressure

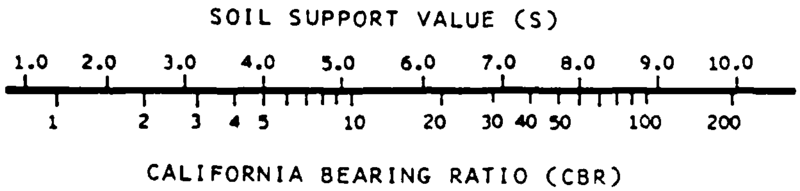


Figure 5.2. Soil Support Values [1].

Table 5.4. Soil Support Values [5].

RELATIONSHIPS BETWEEN SOIL TYPES AND BEARING VALUES*			
Type of Soil	*Subgrade Strength*	*k-Value Range, psi*	*Soil Support Value (S.S.V.)*
Silts and clays of high compressibility natural density (uncompacted)	*Very low*	*50*	*1.7*
Silts and clays of high compressibility natural Density (compacted)	*Low*	*100*	*2.7*
Fine grain soils in which silt and clay size particles predominate (compacted)	*Medium*	*100 - 150*	*2.7 - 4.3*
Poorly graded sands and soils that are predominantly sandy with moderate amounts of silts and clays (compacted)	*High*	*150 - 220*	*4.3 - 6.0*

support values based on widely varying soil characteristics. Each organization must adopt a means of evaluating the soil support values which best suit the soils encountered in a particular region.

5.2.3.3 Terminal Serviceability Index

A significant concept developed by the Road Test was the Terminal Serviceability Index (P_t). The P_t is a qualitative measure of the final condition of a pavement at the end of its design service life. The P_t scale is from total falure at 1.5 to outstanding at 5.0; 3.5 to 5.0 corresponds to poor to outstanding new construction, respectively. For design, a P_t of 2.5 applies to the minimum serviceability of an interstate highway; similarly, a P_t of 2.0 applies to secondary roads.

5.2.3.4 Regional Factors

In an effort to apply the general design equations developed via the Road Test to other regions, a regional factor was introduced such that environmental factors not encountered in Illinois could be incorporated into the design. The regional factor can incorporate the following parameters [1]:

a) topography

b) similarity to the Road Test location

c) rainfall

d) frost penetration

e) temperature

f) groundwater table

g) subgrade type

h) engineering judgment

i) type of highway structure

j) subsurface drainage

Figure 5.3 is a general guide for the selection of a regional factor. The scale varies from 0.5 to 4.8. The lowest values apply to permanently frozen or consistently dry roadbed materials. The upper values apply to severe frost heave conditions and other mechanisms which rapidly accelerate pavement deterioration. The value used for the road test was 1.0. AASHTO recommends the following as a crude guide.

Table 5.5. Regional Factors [1].

Condition	*R* value
Roadbed materials frozen to depth of 5 in. or more	0.2-1.0
Roadbed materials dry, summer and fall	0.3-1.5
Roadbed materials wet, spring thaw	4.0-5.0

Historical data of pavement performance in relation to the number of annual freeze-thaw cycles, steep grades with large volumes of heavy truck traffic, and areas of concentrated turning and stopping movements can be useful in evaluating an appropriate regional factor.

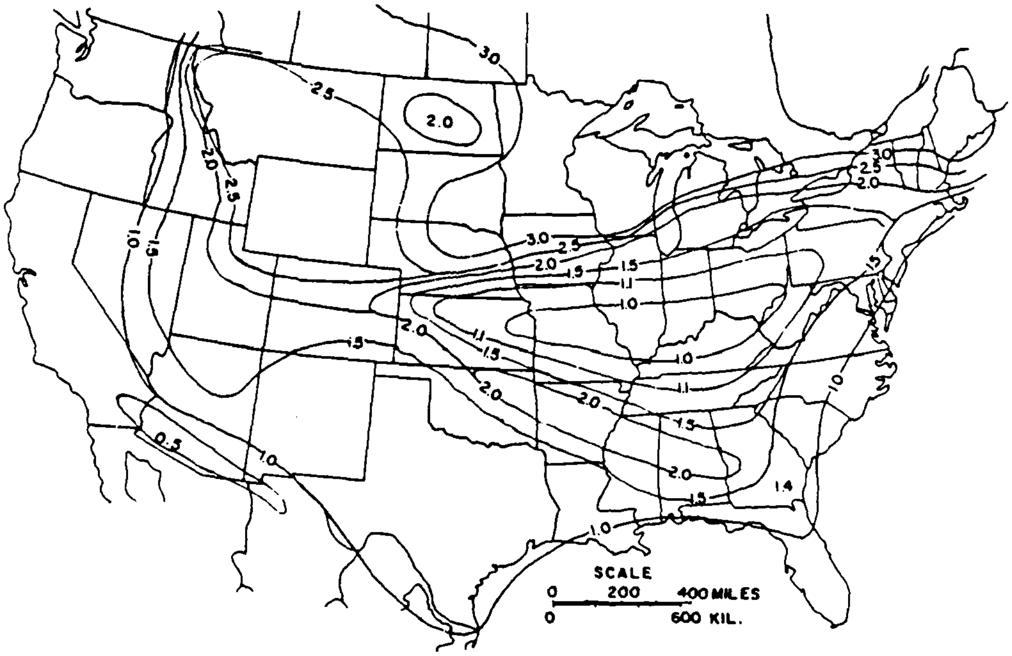


Figure 5.3. Generalized Regional Factors [4].

5.2.3.5 Structural Number

The E-18s, regional factor, soil support value, and terminal serviceability index represent various components influencing the design of a flexible pavement. To combine the above parameters into a value which could be translated into a pavement design, a structural number (SN) was introduced. The structural number is a value calculated from the above parameters and is the sum of the layer thicknesses multiplied by their appropriate structural coefficients.

$$SN = a_1D_1 + a_2D_2 + \ . \ . \ . + a_iD_i$$

where,

a_i = structural coefficient of layer i

D_i = thickness of layer i (inches)

The structural number is abstract but relates to the strength of the section.

5.2.3.6 Structural Coefficient

The structural coefficient is a measure of a layers ability to transmit load. As previously discussed, the surface course will have a higher structural coefficient than a layer less capable of distributing a load to a lower layer. Tables 5.6 through 5.9 relate structural coefficients to various construction materials. Many service organizations develop their own correlations to best suit their situation.

Table 5.6. Structural Coefficients [1].

Structural Layer Coefficients Proposed by AASHO Committee on Design, October 12, 1961

Pavement Component	Coefficient[3]
Surface Course	
Roadmix (low stability)	0.20
Plantmix (high stability)	0.44*
Sand Asphalt	0.40
Base Course	
Sandy Gravel	0.07[2]
Crushed Stone	0.14*
Cement-Treated (no soil-cement)	
Compressive strength @ 7 days	
650 psi or more[1] (4.48MPa)	0.23[2]
400 to 650 psi (2.76 to 4.48MPa)	0.20
400 psi or less (2.76MPa)	0.15
Bituminous-Treated	
Coarse-Graded	0.34[2]
Sand Asphalt	0.30
Lime-Treated	0.15-0.30
Subbase Course	
Sandy Gravel	0.11*
Sand or Sandy-Clay	0.05-0.10

* Established from AASHO Road Test Data

[1] Compressive strength at 7 days.

[2] This value has been estimated from AASHO Road Test data, but not to the accuracy of those factors marked with an asterisk.

[3] It is expected that each state will study these coefficients and make such changes as experience indicates necessary.

Table 5.7. Selected Structural Coefficients Used by Various Transportation Organizations in the AASHO Interim Guide Design Method [6].

Pavement Component	Structural Coefficient			
	Fla.	Ga.	Md.	S.C.
I. Surface and Binder Course (a_1)				
Asphalt Concrete	0.2 - 0.4 (5)	0.44 (1)	0.44	0.44
Bituminous Surfacing	-	-	-	0.35
II. Base Course (a_2)				
Asphalt Concrete	0.21 - 0.30 (4)	0.30	0.28	0.34
Sand-Asphalt		0.12	0.28	0.20 - 0.25
Soil Cement	0.22	0.20	0.28	0.20
Graded Aggregate		0.18 (2)	0.14	0.12 - 0.20
Cement Stabilized Graded Aggregate		0.22	0.28	0.34
Sand Aggregate	-	-	0.14	-
Sand-Clay CBR $\geq$ 49	0.12	-	-	-
Limerock CBR $\geq$ 80	0.15	-	-	-
Limerock Stabilized Base. CBR $\geq$ 56	0.12	-	-	-
III. Subbase (a_3)				
Graded Aggregate		0.14	-	-
Topsoil or Sand-Clay		0.10	-	-
Gravel or Screenings	-	-	0.07	-
Soil Aggregate	-	-	-	0.08 - 0.12
Cement Stabilized Earth	-	-	-	0.15

1. Georgia uses a coefficient of 0.44 for surface and binder to a depth of 4.5 in. (110 mm).
2. When compacted to 100% of T-180 density.
3. Subbase coefficients are used in Georgia below a depth of 12 in. (300 mm).
4. The Florida DOT uses the following structural coefficients for different base mixes: (1) Type I, 500 lb. Marshall stability, $a_2 = 0.21$; (2) Type II, 750 lb. Marshall stability, $a_2 = 0.25$; (3) Type III, 1,000 lb. Marshall stability, $a_2 = 0.30$.
5. The Florida DOT uses the following structural coefficients for different surface mixes: Type S1, 1,000 lb. Marshall stability, $a_1 = 0.40$; Type S2, 1,000 lb. Marshall stability, $a_2 = 0.20$; and Type S3, 750 lb. Marshall stability, $a_1 = 0.30$.

Table 5.8. Pavement Coefficients for Flexible Section Design, Louisiana [1]

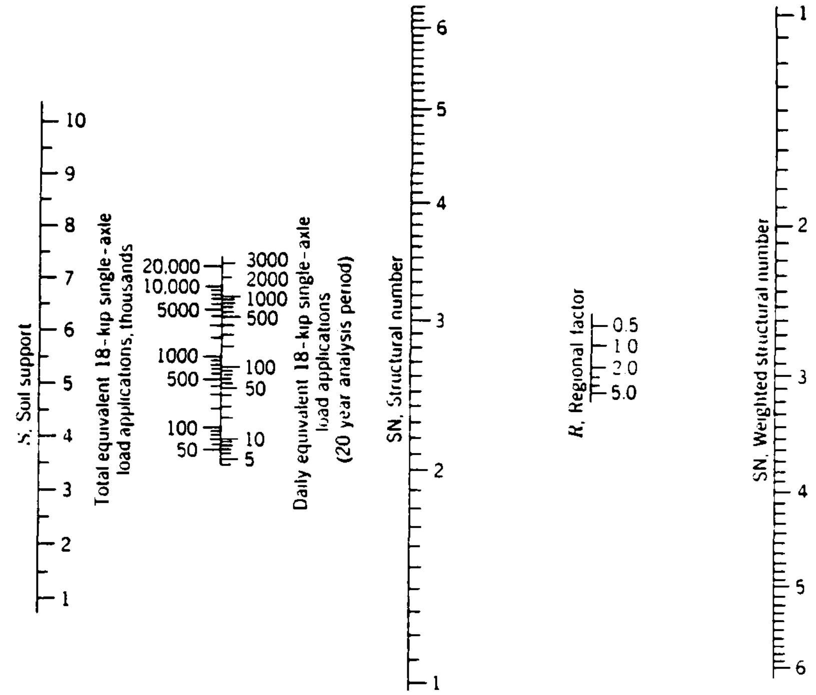
		Strength	Coefficient
I.	*SURFACE COURSE*		
	Asphaltic Concrete		
	Types 1, 2 and 4 BC and WC	1000+	0.40
	Types 3 WC	1800+	0.44
	BC	1500+	0.43
II.	*BASE COURSE*		
	UNTREATED		
	Sand Clay Gravel – Grade A	3.3–	0.08
	Sand Clay Gravel – Grade B	3.5–	0.07
	Shell and Sand – Shell	2.2–	0.10
	CEMENT-TREATED		
	Soil-Cement	300 psi+	0.15
	Sand Clay Gravel – Grade B	500 psi+	0.18
	Shell and Sand – Shell	500 psi+	0.18
	Shell and Sand – Shell	650 psi+	0.23
	LIME-TREATED		
	Sand Shell	2.0–	0.12
	Sand Clay Gravel – Grade B	2.0–	0.12
	ASPHALT-TREATED		
	Hot-Mix Base Course (Type 5A)	1200+	0.34
	Hot-Mix Base Course (Type 5B)	800+	0.30
III.	*SUBBASE COURSE*		
	Lime-Treated Sand Clay Gravel – Grade B	2.0–	0.14
	Shell and Sand-Shell	2.0–	0.14
	Sand Clay Gravel – Grade B	3.5–	0.11
	Lime-Treated Soil	3.5–	0.11
	Old Gravel or Shell Roadbed (8" thickness) (200 mm)	–	0.11
	Sand (R-Value)	55+	0.11
	Suitable Material–A–6 (PI = 15–)	–	0.04

Table 5.9. Recommended AASHTO Interim Guide Structural Coefficients for Thickness Design [6].

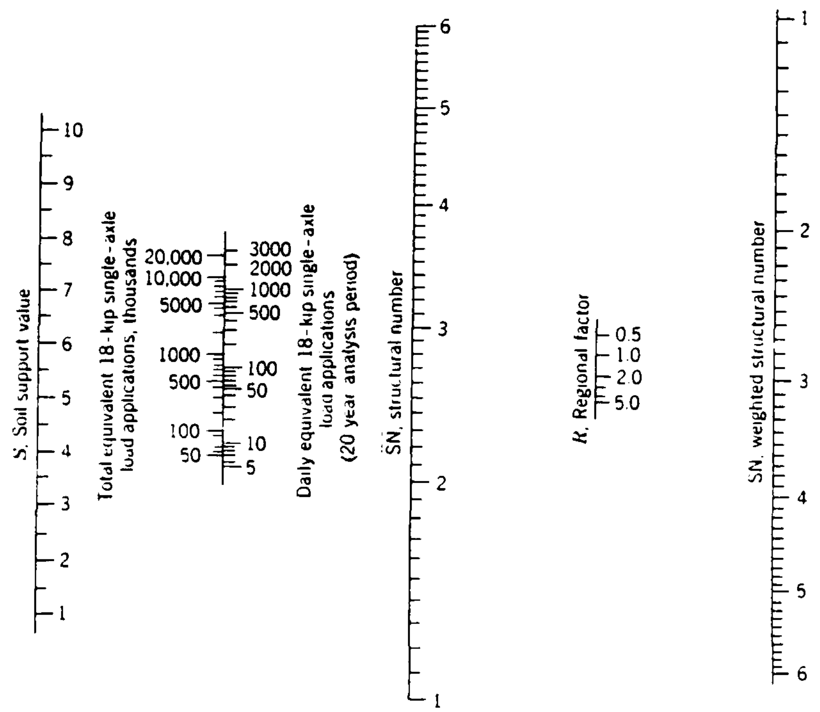
Structural Layer	Class	Structural Coefficient	General Requirements
1. Surface and Binder Course (Weighted Avg.)			
Asphalt Concrete	1	0.48	> 6.0% AC; 2-4% Air Voids; > 1500 lb. Marshall Stability (1)
	2	0.44	≥ 4.8% AC; 2-6% Air Voids; > 1200 lb. Marshall Stability
	3	0.35	≤ 4.4% AC; 2-8% Air Voids; > 700 lb. Marshall Stability
Sand Asphalt	1	0.35	> 5.8% AC; <14% Air Voids; > 550 lb. Marshall Stability (1)
	2	0.27	< 4.8% AC; <18% Air Voids; > 400 lb. Marshall Stability
2. Base Course			
Crushed Stone (Untreated)	1	0.14	Well graded; 1-1/2 in. or greater top size; 3-8% fines; 100% T-180 compaction
Asphalt Concrete	1	0.34	> 5.8% AC; 2-4% Air Voids; > 1200 lb. Marshall Stability (1)
	2	0.28	< 4.8% AC; <8% Air Voids; > 1200 lb. Marshall Stability
Sand Asphalt	1	0.25	> 5.8% AC; 14% Air Voids; > 600 lb. Marshall Stability (1)
	2	0.17	< 4.5% AC; 18% Air Voids; > 350 lb. Marshall Stability
Sand Cement	1	0.24	> 600 psi, 7 day Compressive Strength
	2	0.18	> 400 psi, 7 day Compressive Strength
3. Inverted Structural Section - Experimental (2)			
Unstabilized Sand Base		0.10 to 0.12	Clean, medium to coarse sand with less than 4 to 8 percent fines
Unstabilized sand - crushed stone blend		0.16	

NOTES: 1. Given Marshall Stabilities are for a 50 blow Mix Design

2. Structural section consisting of unstabilized clean sand or crushed stone placed between a sand-cement base and asphalt concrete surface course. Use structural coefficients for sand-cement base and asphalt concrete surface course given above.



Design chart for flexible payments, $p_t = 2.0$



Design chart for flexible pavements, $p_t = 2.5$

Figure 5.4. AASHO Flexible Pavement Design Nomographs [3].

5.2.4 AASHTO Equation

The general equation developed by AASHTO is as follows:

$$\log W_{18} = 9.36 \log (SN+1) - .2 + \frac{\log [(4.2-P_t)/2.7]}{.4 + \frac{1094}{(SN+1)^{5.19}}}$$

$$+ \log \frac{1}{R} + .372 (S_i - 3.0)$$

where,

W_{18} = E-18's, single axle loads

SN = structural number

P_t = terminal serviceability index

R = regional factor

S_i = soil support value

(log = natural logarithm)

The structural number is calculated by iterative trials given W_{18}, P_t, R, and S_i.

Nomographs were developed for terminal serviceability indexes of 2.0 and 2.5 and are presented in Figure 5.4. After calculating SN with S_i and W_{18}, a weighted or design SN is calculated using the regional factor.

Figure 5.5 relates the variation of wheel load type to the structural number with all other parameters normalized to the road test; i.e., S_i = 3.0 and R = 1.0.

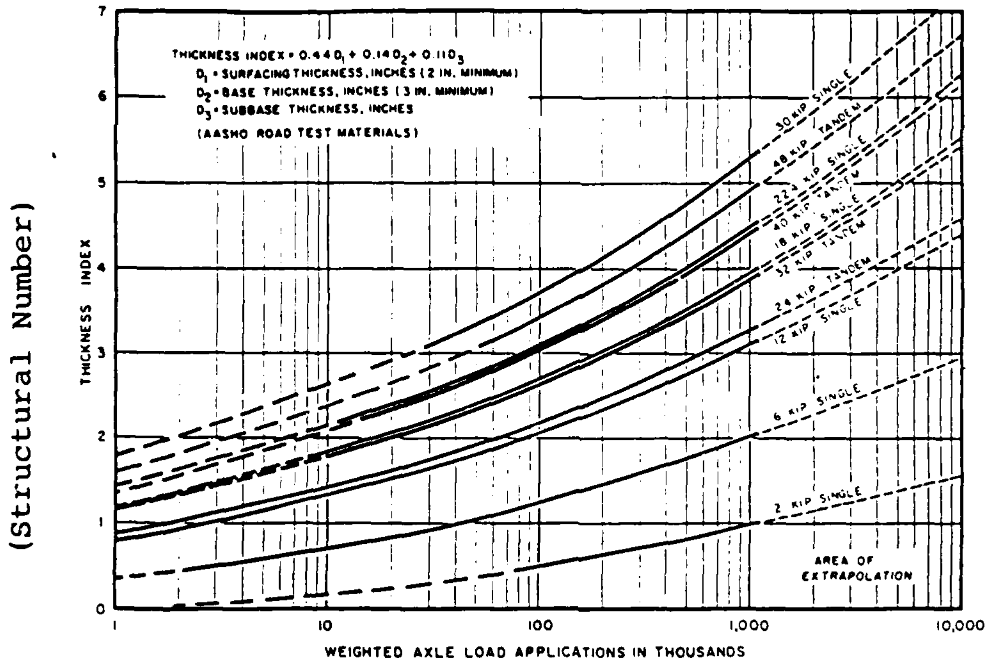


Figure 5.5. AASHO road test relationship between thickness index and axle loads at $p = 2.5$. [2].

5.3 Program Rationale

AASHTO 1 is designed to provide the user the ability to approach the design problem by two avenues. Given the regional factor, soil support value, and terminal serviceability index, the user can input the pavement layer characteristics and calculate the number of equivalent single axle 18-kip loads the pavement can expect to endure. Similarly, the program can calculate the required thickness of a layer given the regional factor, soil support value, terminal serviceability index, E-18's, and the characteristics of the other layers (see Figure 5.6).

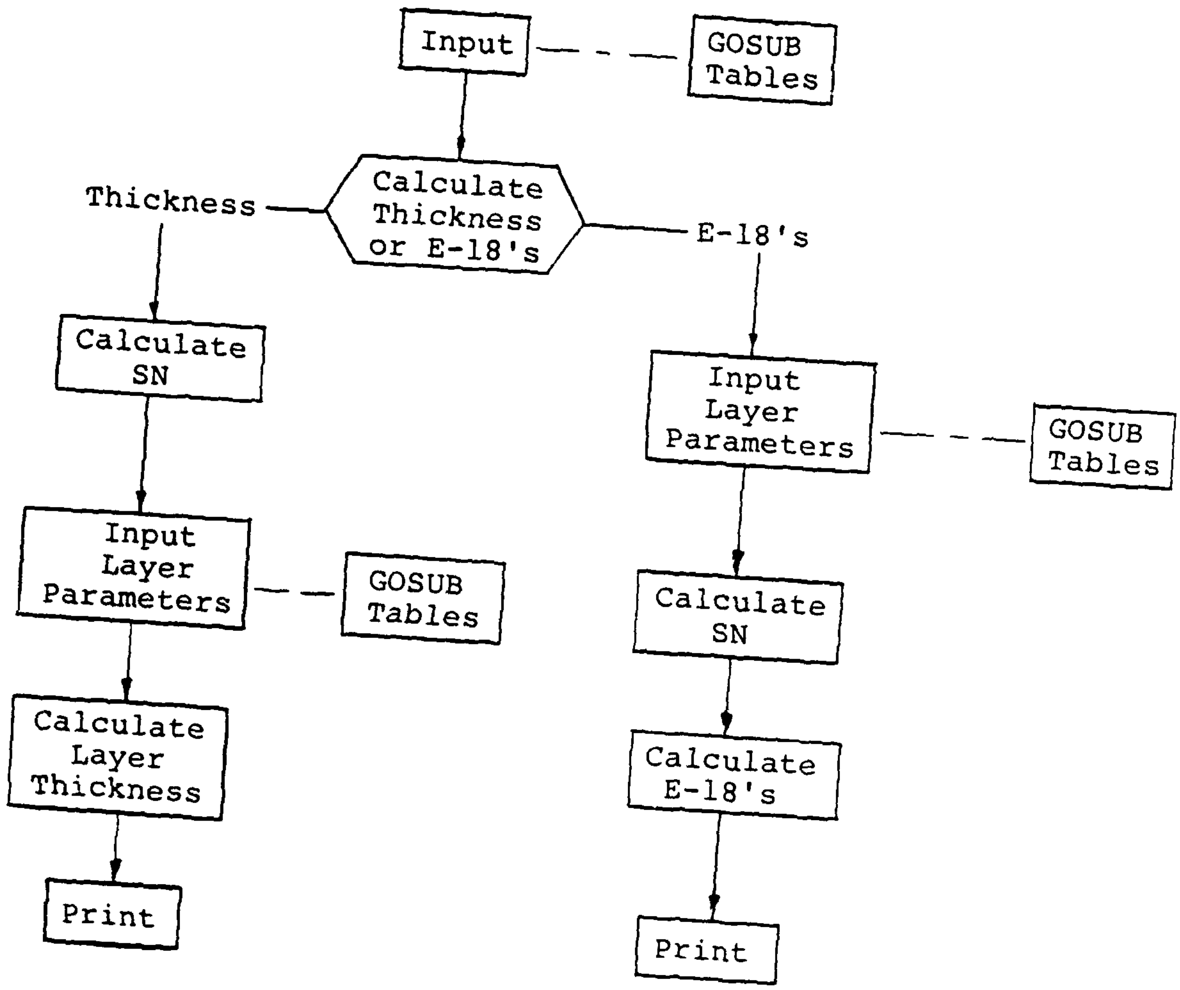


Figure 5.6. AASHTO 1 Flow Chart.

Originally, the author intended to create a matrix of possible layer thicknesses but due to the limited capacity of the miniature computer, this idea was aborted. The program was then designed to allow the user to quickly change thicknesses and structural coefficients in successive runs without inputting repetitive data.

The output was designed to resemble a layered system with input variables and other calculated data presented below the output. This format allows the user to correlate data from different runs with the maximum of ease.

5.4 Program Use and Limitations

5.4.1 General

AASHTO 1 is user oriented. Input is prompted by statements and questions which clearly identify the input requirements. As with any program, the user should have the input ready prior to running the program. If several runs are to be executed, the user should prepare a chart of required input variables. This method will eliminate most errors associated with mistaken or improper variable input.

5.4.2 Input

As previously mentioned, AASHTO 1 is composed of two parts. One portion of the program calculates a required thickness given all other data, and the second portion calculates the equivalent single axle 18-kip loadings. The user will be prompted to choose which option is to be run. The user must input the number of runs to be made with the

portion of the program previously specified. After the runs are completed, the user may then opt to run the alternate portion of the program or more runs of the same. Each time a new set of runs are specified, all input must be re-entered.

The following is a list of required input. The input differences between the two programs will be discussed later in this section.

a) soil support value

b) terminal serviceability index

c) regional factor

d) E-18's

e) number of layers

f) layer number for thickness calculation

g) layer number

h) structural coefficient

i) layer thickness

When the user has specified an E-18 calculation, input d) and f) will be emitted; conversely, for a layer thickness calculation input i) will be emitted for the layer specified for thickness calculation. Although it is recommended to number the layers successively from #1 for the top layer to #i for the ith layer, this is not required. The user will find the output format suited to numbering layers in this fashion.

5.4.3 Options

AASHTO 1 provides the user with tables of typical values of soil support, terminal serviceability index, regional factor, E-18's, and structural coefficients. The user may access these charts by inputting 0 (zero) instead of the non-zero variable requested. After inputting 0, the chart will appear on the monitor. When the user is finished reviewing the chart, the user will again be prompted to input the required variable. The charts are derived from those presented in Section. 5.2.

As previously described, the user has the option of calculating a layer thickness or the number of equivalent single-axle 18-kip loads.

5.4.4 Limitations

The user is limited to specifying ten layers. This limitation is due to memory capacity. If the user requires more layers, there are no constraints in the program to prevent inputting more than ten. The user should not attempt to input more than ten layers. If an out-of-memory error results, the user must reduce the number of layers.

The inherent limitation of AASHTO 1 is the basis and validity of the AASHO Road Test equations. The user is urged to study reference #4 for an evaluation of the guide.

5.5 Program List

```
2  HOME
5  SPEED= 150
10  PRINT "          **********"
12  PRINT "          * AASHTO *"
14  PRINT "          **********"
16  PRINT : PRINT : PRINT
18  PRINT "DANA K. EDDY, 578-80-8378
20  PRINT "GA. INSTITUTE OF TECHNOLOGY"
22  PRINT "SCHOOL OF CIVIL ENGINEERING"
24  PRINT "DEPARTMENT OF GEOTECHNICAL ENGINEERING"
26  PRINT : PRINT : PRINT
28  PRINT "SYSTEM HARDWARE: APPLE II PLUS (64K)"
30  PRINT "SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE"
32  PRINT "PROGRAM DATE: JULY, 1983"
34  PRINT : PRINT
36  PRINT : PRINT
38  PRINT "AASHTO IS BASED ON THE AASHTO INTERIM GUIDE FOR THE DESIGN OF F
     LEXIBLE PAVEMENT STRUCTURES, 1972."
39  PRINT : PRINT : PRINT "(PRESS THE SPACE BAR TO CONTINUE)"
40  POKE  - 16368,0
41 CH =  PEEK ( - 16384)
42  IF CH <  > 160 GOTO 40
44  SPEED= 255
46  HOME
100  PRINT "USER INPUT QUESTIONS AND COMMANDS WHICH ARE FOLLOWED BY (*) AR
     E SUPPLEMENTED BY LISTS AND TABLES.  TO ACCESS THE LIST OR TABLE TYPE
      (0) INSTEAD OF THE APPROPRIATE VALUE OF THE VARIABLE REQUESTED."
110  PRINT : PRINT
115  INPUT "PROBLEM HEADING  ";H$
117  PRINT : PRINT
120  INPUT "TO CALCULATE THE THICKNESS OF A PARTICULAR LAYER, TYPE (1); TO
      CALCULATE THE MAXIMUM NUMBER OF EQUIVALENT 18-KIP LOADS, TYPE (2). "
     ;BB
130  PRINT : PRINT
140  INPUT "HOW MANY TRIALS DO YOU WANT TO RUN? ";Z
150  PRINT : PRINT
160  IF BB = 2 THEN 190
170  INPUT "WHAT IS THE CALCULATION TOLERANCE (REC'D; .01). ";TL
180  PRINT : PRINT
190  INPUT "SOIL SUPPORT VALUE (*) = ";SI
200  PRINT : PRINT
210  IF SI > 0 GOTO 240
220  GOSUB 2000
230  GOTO 190
240  INPUT "TERMINAL SERICEABILITY INDEX (*) = ";PT
250  PRINT : PRINT
260  IF PT > 0 GOTO 290
270  GOSUB 3000
280  GOTO 240
290  INPUT "REGIONAL FACTOR (*) = ";RI
300  PRINT : PRINT
310  IF RI > 0 GOTO 340
320  GOSUB 4000
```

```
330  GOTO 290
340  IF BB = 2 GOTO 1010
350  INPUT "# OF EQUIVALENT SINGLE AXLE 18-KIP WHEEL LOADS (*) = ";WI
352  PRINT : PRINT
355  IF WI > 0 GOTO 370
360  GOSUB 5000
365  GOTO 350
370 X = 4
375 XX = 1:YY = 0:ZZ = 0
380 A1 =  LOG (WI) / 2.3026
390 A2 = .2
400 A3 =  LOG ((4.2 - PT) / 2.7) / 2.3026
410 A4 =  LOG (1 / RI) / 2.3026
420 A5 = .375 * (SI - 3.0)
430 AA = A1 + A2 - A4 - A5
440 AB = (4.065 *  LOG (X) * (.4 * X ^ 5.19 + 1094) + A3 * X ^ 5.19) / (.4
     * X ^ 5.19 + 1094)
442 XX = XX + 1
444  IF XX > 500 GOTO 510
450  IF AB >  = AA - TL / 2 AND AB <  = AA + TL / 2 GOTO 510
460  IF AB < AA GOTO 490
470  IF YY = 0 GOTO 474
471  IF YY = 1 AND ZZ = 1 GOTO 474
472 TL = TL / 10
474 X = X - TL
476 ZZ = 1
480  GOTO 440
490  IF ZZ = 0 GOTO 494
491  IF ZZ = 1 AND YY = 1 GOTO 494
492 TL = TL / 10
494 X = X + TL
496 YY = 1
500  GOTO 440
510 SN = X - 1
512 NN = SN * 100
513 NN =  INT (NN)
514 NN = NN / 100
520  FOR H = 1 TO Z
521  HOME
524  PRINT "%%%%%%%%"
525  PRINT "TRIAL #"H
526  PRINT "%%%%%%%%"
527  PRINT : PRINT
528  PRINT "STRUCTURAL NUMBER ="NN
529  PRINT : PRINT
530  INPUT "SPECIFY # OF LAYERS (MAX-10). ";N
540  PRINT : PRINT
550  INPUT "LAYER # FOR THICKNESS CALCULATION. ";L
560  PRINT : PRINT
570  FOR I = 1 TO N
575  PRINT "********************"
```

```
577  PRINT
580  INPUT "LAYER #. ";Y
590  PRINT : PRINT
600  INPUT "STRUCTURAL COEFFICIENT (*) = ";A(Y)
610  PRINT : PRINT
620  IF A(Y) > 0 GOTO 645
630  GOSUB 6000
640  GOTO 600
645  IF I = L GOTO 700
650  INPUT "LAYER THICKNESS (INCHES) = ";D(Y)
660  PRINT : PRINT
670  IF D(Y) > 0 GOTO 700
680  GOSUB 7000
690  GOTO 650
700  NEXT I
710 SC = 0
720  FOR I = 1 TO N
730  IF I = L GOTO 750
740 SC = SC + D(I) * A(I)
750  NEXT I
760  IF SC < SN GOTO 830
770  PRINT "** WARNING **  INPUT LAYERS SATISFY MINIMUM STRUCTURAL REQUIRE
     MENTS."
780  PRINT : PRINT
790  INPUT "TYPE (1) TO REENTER VARIABLES. TYPE (2) TO END PROGRAM. ";DD
800  PRINT : PRINT
810  IF DD = 1 GOTO 520
820  GOTO 1490
830 D(L) = SN / A(L)
840  FOR I = 1 TO N
850  IF I = L GOTO 870
860 D(L) = D(L) - A(I) * D(I) / A(L)
870  NEXT I
880 D(L) = D(L) * 100
890 D(L) =  INT (D(L))
900 D(L) = D(L) / 100
902 L$ =  CHR$ (4): PRINT L$;"PR#          1"
905  PRINT : PRINT : PRINT
906  PRINT "%%%%%%%%%%%%%%%%%%%%%%%%%%%"
907  PRINT H$
908  PRINT "%%%%%%%%%%%%%%%%%%%%%%%%%%%"
909  PRINT : PRINT
910  PRINT "TRIAL #"H
915  PRINT "*********"
920  PRINT : PRINT
930  PRINT "LAYER","STR'L COEFF.","THICKNESS"
950  FOR I = 1 TO N
960  PRINT  SPC( 2)I,A(I),D(I)
970  NEXT I
980  PRINT
990  PRINT "STRUCTURAL NUMBER ="SN
```

```
992  PRINT
995  PRINT "EQUIVALENT SINGLE AXLE 18-KIP LOAD ="WI
997  PRINT : PRINT : PRINT
998  PRINT L$;"PR#0"
1000  NEXT H
1005  PRINT L$;"PR#0"
1006  GOTO 1370
1010  FOR H = 1 TO Z
1015  HOME
1016  PRINT "%%%%%%%%"
1017  PRINT "TRIAL #"H
1018  PRINT "%%%%%%%%"
1019  PRINT : PRINT
1020  INPUT "SPECIFY # OF LAYERS (MAX-10) ";N
1030  PRINT : PRINT
1040  FOR I = 1 TO N
1045  PRINT "********************"
1047  PRINT
1050  INPUT "LAYER # =";Y
1060  PRINT : PRINT
1070  INPUT "STRUCTURAL COEFFICIENT (*) =";A(Y)
1080  PRINT : PRINT
1090  IF A(Y) > 0 GOTO 1120
1100  GOSUB 6000
1110  GOTO 1070
1120  INPUT "LAYER THICKNESS (INCHES) = ";D(Y)
1130  PRINT : PRINT
1140  IF D(Y) > 0 GOTO 1161
1150  GOSUB 7000
1160  GOTO 1120
1161  NEXT I
1163 SN = 0
1165  FOR I = 1 TO N
1167 SN = SN + A(I) * D(I)
1169  NEXT I
1170 B2 = 9.36 *  LOG (SN + 1) / 2.3026
1180 B3 = .2
1190 B4 =  LOG ((4.2 - PT) / 2.7) / 2.3026
1200 B5 = .4 + 1094 / (SN + 1) ^ 5.19
1210 B6 =  LOG (1 / RI) / 2.3026
1220 B7 = .372 * (SI - 3.0)
1230 B1 = B2 - B3 + B4 / B5 + B6 + B7
1240 WI =  EXP (2.3026 * B1)
1250 WI =  INT (WI)
1260 L$ =  CHR$ (4): PRINT L$;"PR#1"
1261  PRINT : PRINT : PRINT
1262  PRINT "%%%%%%%%%%%%%%%%%%%%%%%%%%"
1263  PRINT H$
1264  PRINT "%%%%%%%%%%%%%%%%%%%%%%%%%%"
1265  PRINT : PRINT
1270  PRINT "TRIAL #"H
```

```
1272  PRINT "********"
1280  PRINT
1285  PRINT "LAYER","STR'L COEFF.","THICKNESS"
1290  FOR I = 1 TO N
1295  PRINT  SPC( 3)I,A(I),D(I)
1300  NEXT I
1310  PRINT : PRINT
1320  PRINT "STRUCTURAL NUMBER ="SN
1330  PRINT
1340  PRINT "EQUIVALENT SINGLE AXLE 18-KIP LOADS ="WI
1350  PRINT L$;"PR#0"
1360  NEXT H
1370 L$ =  CHR$ (4): PRINT L$;"PR#1"
1380  PRINT : PRINT
1390  PRINT "SOIL SUPPORT VALUE ="SI
1400  PRINT
1410  PRINT "TERMINAL SERVICEABILITY INDEX ="PT
1420  PRINT
1430  PRINT "REGIONAL FACTOR ="RI
1435  PRINT L$;"PR#0"
1440  INPUT "DO YOU WANT TO RUN ANY MORE TRIALS (0=NO, 1=YES)? ";Q1
1450  PRINT : PRINT
1460  IF Q1 = 0 GOTO 1490
1470  INPUT "FOR A LAYER THICKNESS CALCULATION, TYPE(1); FOR AN 18-KIP LOA
     DING CALCULATION, TYPE(2). ";BB
1475  PRINT : PRINT
1480  GOTO 140
1490  HOME
1495  PRINT "THANK YOU FOR USING AASHTO"
1500  PRINT
1510  PRINT "BYE-BYE"
1520  END
2000  HOME
2101  PRINT  TAB( 12)"SOIL SUPPORT VALUE"
2102  PRINT  TAB( 17)"(AASHO)"
2103  PRINT  TAB( 12)"******************"
2104  PRINT
2105  PRINT "  SOIL   DYNAMIC STATIC  AASHO  MODULUS"
2106  PRINT " SUPPORT   CBR     CBR   3 PT.     MR"
2107  PRINT "  VALUE                            PSI"
2108  PRINT
2109  PRINT  TAB( 5)"8 ---- 60  --- 78  - 14.5 --  NA"
2110  PRINT  TAB( 5)"7 ---- 35  --- 36  - 9.75 --  NA"
2111  PRINT  TAB( 5)"6 ---- 17  --- 19  - 6.75 -- 9300"
2112  PRINT  TAB( 5)"5 ----  8  --- 11  - 4.5  -- 6400"
2113  PRINT  TAB( 5)"4 ----  5  ---  6  - 2.5  -- 4400"
2114  PRINT  TAB( 5)"3 ----  3  --- 2.8 - 1.25 -- 3000"
2115  PRINT  TAB( 5)"2 ---- 1.5 --- 1.8 - 0.50 -- 2100"
2116  PRINT  TAB( 5)"1 ---- 0.5 --- 0.5 - 0.25 --  NA"
2120  PRINT : PRINT : PRINT
2122  PRINT : PRINT
2130  IF C1 = 1 GOTO 2300
```

```
2200  PRINT "(TO CONTINUE LIST, PRESS SPACE BAR)"
2210  POKE  - 16368,0:CJ =  PEEK ( - 16384)
2215  IF CJ <  > 160 GOTO 2210
2300  HOME
2301  PRINT  TAB( 12)"SOIL SUPPORT VALUE"
2302  PRINT  TAB( 17)"(GA DOT)"
2303  PRINT  TAB( 12)"******************"
2304  PRINT
2305  PRINT  TAB( 6)"REGION          SOIL SUPPORT VALUE"
2306  PRINT
2307  PRINT  TAB( 7)"PIEDMONT              2.5-3.0"
2308  PRINT
2309  PRINT  TAB( 7)"COASTAL PLAIN         4.0-5.0"
2310  PRINT
2311  PRINT  TAB( 7)"VALLEY & RIDGE        2.5-3.0"
2320  PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT : PRINT
     : PRINT
2322  IF C1 = 1 GOTO 2945
2325  PRINT "TO CONTINUE, PRESS SPACE BAR"
2330  POKE  - 16368,0:CK =  PEEK ( - 16384)
2335  IF CK <  > 160 GOTO 2330
2900  IF C1 = 1 GOTO 2945
2920  HOME
2925  INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?";C1
2930  IF C1 = 0 GOTO 2950
2935 L$ =  CHR$ (4): PRINT L$;"PR#1"
2940  GOTO 2101
2945  PRINT L$;"PR#0"
2950 C1 = 0
2955  RETURN
3000  HOME
3101  PRINT  TAB( 4)"TERMINAL SERVICEABILITY INDEX, PT"
3102  PRINT  TAB( 16)"(AASHTO)"
3103  PRINT  TAB( 4)"*********************************"
3104  PRINT
3105  PRINT  TAB( 4)"CLASSIFICATION                      PT"
3106  PRINT
3107  PRINT  TAB( 4)"PRIME ROUTES, MAJOR               2.5"
3108  PRINT  TAB( 5)"ARTERIALS,EXPRESSWAYS"
3109  PRINT
3110  PRINT  TAB( 4)"PRIME SECONDARY ROUTES,           2.25"
3111  PRINT  TAB( 5)"IND. & COMM. STREETS"
3112  PRINT
3113  PRINT  TAB( 4)"MINOR SECONDARY ROUTES,           2.0"
3114  PRINT  TAB( 5)"RESIDENTIAL STREETS,"
3115  PRINT  TAB( 5)"PARKING LOTS"
3116  PRINT
3117  PRINT  TAB( 4)"FAILURE, DEFINED BY               1.5"
3118  PRINT  TAB( 5)"AASHTO"
3200  PRINT : PRINT
3205  PRINT : PRINT
```

```
3207  IF D1 = 1 GOTO 3945
3210  PRINT "TO CONTINUE, PRESS SPACE BAR"
3220  POKE  - 16368,0:DI =  PEEK ( - 16384)
3225  IF DI <  > 160 GOTO 3220
3230  HOME
3235  INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?";D1
3240  IF D1 = 0 GOTO 3950
3935 L$ =  CHR$ (4): PRINT L$;"PR#1"
3940  GOTO 3101
3945  PRINT L$;"PR#0"
3950 D1 = 0
3955  RETURN
4000  HOME
4101  PRINT  TAB( 6)"RECOMMENDED REGIONAL FACTORS"
4102  PRINT  TAB( 15)"FOR GEORGIA"
4103  PRINT  TAB( 6)"******************************"
4104  PRINT
4105  PRINT  TAB( 10)"AREA            FACTOR"
4106  PRINT
4107  PRINT  TAB( 6)"COASTAL PLAINS      1.4-1.7"
4108  PRINT  TAB( 7)"-SAVANNAH            1.7"
4109  PRINT
4110  PRINT  TAB( 6)"PIEDMONT            1.5-1.8"
4111  PRINT  TAB( 7)"-ATLANTA             1.8"
4112  PRINT  TAB( 7)"-MACON               1.6"
4113  PRINT  TAB( 7)"-COLUMBUS            1.8"
4114  PRINT  TAB( 7)"-AUGUSTA             1.5"
4115  PRINT
4116  PRINT  TAB( 6)"VALLEY & RIDGE      2.0-2.2"
4400  PRINT : PRINT : PRINT
4410  PRINT : PRINT
4415  IF E1 = 1 GOTO 4945
4420  PRINT "TO CONTINUE, PRESS SPACE BAR"
4430  POKE  - 16368,0:EI =  PEEK ( - 16384)
4440  IF EI <  > 160 GOTO 4430
4445  HOME
4450  INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? ";E1
4455  IF E1 = 0 GOTO 4950
4460 L$ =  CHR$ (4): PRINT L$;"PR#1"
4465  GOTO 4101
4945  PRINT L$;"PR#0"
4950 E1 = 0
4955  RETURN
5000  HOME
5101  PRINT "   EQUIVALENT SINGLE AXLE 18-KIP LOADS"
5102  PRINT  TAB( 11)"20 YEAR DESIGN LIFE"
5103  PRINT "   **********************************"
5104  PRINT
5105  PRINT "  CLASS   TYPE PVMT        EQUIVALENT"
5106  PRINT  TAB( 28)"18-KIP LOAD*"
5107  PRINT "  LIGHT   PARKING, CITY"
5108  PRINT  TAB( 11)"STREET, RURAL   22000-420000"
```

```
5109  PRINT  TAB( 11)"ROADS"
5110  PRINT
5111  PRINT "  MEDIUM  SECONDARY      420000-3000000"
5112  PRINT  TAB( 11)"HIGHWAY"
5113  PRINT
5114  PRINT "  HEAVY   INTERSTATE   3000000-10000000"
5115  PRINT  TAB( 11)"HIGHWAY"
5116  PRINT : PRINT
5117  PRINT
5118  PRINT  TAB( 6)"* BASED ON 580.7 18-KIP LOADS PER"
5119  PRINT  TAB( 7)"1000 TRUCKS"
5120  PRINT : PRINT
5125  IF F1 = 1 GOTO 5945
5130  PRINT "(TO CONTINUE, PRESS SPACE BAR)"
5140  POKE  - 16368,0:FI =  PEEK ( - 16384)
5150  IF FI <  > 160 GOTO 5140
5160  HOME
5170  INPUT "DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? ";F1
5180  IF F1 = 0 GOTO 5950
5190 L$ =  CHR$ (4): PRINT L$;"PR#1"
5200  GOTO 5101
5945  PRINT L$;"PR#0"
5950 F1 = 0
5955  RETURN
6000  HOME
6101  PRINT  TAB( 5)"SELECTED STRUCTURAL COEFFICIENTS"
6102  PRINT  TAB( 5)"**********************************"
6103  PRINT
6104  PRINT " PAVEMENT COMPONENT       STR'L COEFF."
6105  PRINT  TAB( 22)"FLA   GA   MD   SC"
6106  PRINT "  SURFACE COURSE"
6107  PRINT "   ASPHALT CONCRETE .2-.4 .44* .44  .44"
6108  PRINT
6109  PRINT "  BASE COURSE"
6110  PRINT "   ASPHALT CONCRETE .2-.3 .30  .28  .34"
6111  PRINT "   SAND-ASPHALT       -   .12  .28  .25"
6112  PRINT "   SOIL-CEMENT       .22  .20  .28  .20"
6113  PRINT "   GRADED AGGREGATE   -   .18  .14  .15"
6114  PRINT "   CEMENT STABILIZED  -   .22  .28  .34"
6115  PRINT "    GRADED AGGREGATE"
6116  PRINT
6117  PRINT "  SUBBASE"
6118  PRINT "   GRADED AGGREGATE   -   .14   -    -"
6119  PRINT "   TOPSOIL OR SAND-   -   .10   -    -"
6120  PRINT "    CLAY"
6122  PRINT  TAB( 8)"* MAXIMUM DEPTH OF 4.5 IN."
6200  PRINT
6202  IF G1 = 1 GOTO 6945
6205  PRINT "(TO CONTINUE, PRESS SPACE BAR)"
6210  POKE  - 16368,0:GI =  PEEK ( - 16384)
6215  IF GI <  > 160 GOTO 6210
```

```
6220  HOME
6225  INPUT "DO YOU WANT LIST IN HARD COPY (0=NO, 1=YES)?";G1
6230  IF G1 = 0 GOTO 6950
6935 L$ =  CHR$ (4): PRINT L$;"PR#1"
6940  GOTO 6101
6945  PRINT L$;"PR#0"
6950 G1 = 0
6955  RETURN
```

5.6 Variable List (AASHTO 1)

Input

H$ = Heading

Z = # of trials

TL = Tolerance

SI = Soil support value

PT = Terminal serviceability index

RI = Regional factor

WI = Equivalent 18-kip single axle loads

L = Layer # for calculation

Y = Layer #

A(Y) = Structural coefficient

D(Y) = Layer thickness

N = # of layers

D(L) = Layer thickness

Flow Control

BB = Calculate thickness of E-18's

XX = Calculate thickness of E-18's

YY = Calculate thickness of E-18's

ZZ = Calculate thickness of E-18's

Q1 = Table listing

C1 = Table listing

D1 = Table listing

E1 = Table listing

F1 = Table listing

G1 = Table listing

<u>Counters</u>

H = Run #

I = Layer #

<u>Miscellaneous</u>

X = Structural number + 1

AA = Intermediate equation values

AB = Intermediate equation values

NN = Rounded off structural number

SN = Structural number

SC = Structural number (with N-1 layers)

A(1)-A(5) = Intermediate equation values

B(1)-B(7) = Intermediate equation values

5.7 Program Verification

```
]RUN
          ***********
          * AASHTO *
          **********


DANA K. EDDY, 578-80-8378
GA. INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL ENGINEERING
DEPARTMENT OF GEOTECHNICAL ENGINEERING


SYSTEM HARDWARE: APPLE II PLUS (64K)
SYSTEM HARDWARE: DOS 3.3, APPLESOFT BASIC LANGUAGE
PROGRAM DATE: JULY, 1983


AASHTO IS BASED ON THE AASHTO INTERIM GUIDE FOR THE DESIGN OF FLEXIBLE PAVEMENT
STRUCTURES, 1972.

(PRESS THE SPACE BAR TO CONTINUE)
USER INPUT QUESTIONS AND COMMANDS WHICH ARE FOLLOWED BY (*) ARE SUPPLEMENTED BY
LISTS AND TABLES.  TO ACCESS THE LIST OR TABLE TYPE (0) INSTEAD OF THE APPROPRIA
TE VALUE OF THE VARIABLE REQUESTED.

PROBLEM HEADING   AN EXAMPLE PROBLEM

TO CALCULATE THE THICKNESS OF A PARTICULAR LAYER, TYPE (1); TO CALCULATE THE MAX
IMUM NUMBER OF EQUIVALENT 18-KIP LOADS, TYPE (2). 1

HOW MANY TRIALS DO YOU WANT TO RUN? 1

WHAT IS THE CALCULATION TOLERANCE (REC'D; .01). .01
```

SOIL SUPPORT VALUE (*) = 0

SOIL SUPPORT VALUE
(AASHO)
****

SOIL SUPPORT VALUE	DYNAMIC CBR	STATIC CBR	AASHO 3 PT.	MODULUS MR PSI
8	60	78	14.5	NA
7	35	36	9.75	NA
6	17	19	6.75	9300
5	8	11	4.5	6400
4	5	6	2.5	4400
3	3	2.8	1.25	3000
2	1.5	1.8	0.50	2100
1	0.5	0.5	0.25	NA

(TO CONTINUE LIST, PRESS SPACE BAR)

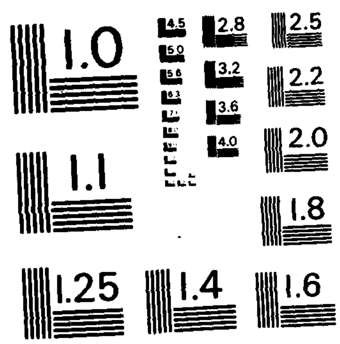
SOIL SUPPORT VALUE
(GA DOT)
****

REGION	SOIL SUPPORT VALUE
PIEDMONT	2.5-3.0
COASTAL PLAIN	4.0-5.0
VALLEY & RIDGE	2.5-3.0

TO CONTINUE, PRESS SPACE BAR
DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? 0
SOIL SUPPORT VALUE (*) = 3

AD-A139 271 COMPUTER APPLICATIONS TO GEOTECHNICAL ENGINEERING(U) 3/3
AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH
D K EDDY AUG 83 AFIT/CI/NR-83-86T

UNCLASSIFIED F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

```
TERMINAL SERICEABILITY INDEX (*) = 0

   TERMINAL SERVICEABILITY INDEX, PT
              (AASHTO)
   ********************************

   CLASSIFICATION                 PT

   PRIME ROUTES, MAJOR           2.5
    ARTERIALS,EXPRESSWAYS

   PRIME SECONDARY ROUTES,       2.25
    IND. & COMM. STREETS

   MINOR SECONDARY ROUTES,       2.0
    RESIDENTIAL STREETS,
    PARKING LOTS

   FAILURE, DEFINED BY           1.5
    AASHTO


TO CONTINUE, PRESS SPACE BAR
DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)? 0
TERMINAL SERICEABILITY INDEX (*) = 2.5


REGIONAL FACTOR (*) = 0

     RECOMMENDED REGIONAL FACTORS
             FOR GEORGIA
     ***************************

        AREA            FACTOR

     COASTAL PLAINS      1.4-1.7
      -SAVANNAH            1.7

     PIEDMONT            1.5-1.8
      -ATLANTA             1.8
      -MACON               1.6
      -COLUMBUS            1.8
      -AUGUSTA             1.5

     VALLEY & RIDGE      2.0-2.2
```

```
TO CONTINUE, PRESS SPACE BAR
DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?  0
REGIONAL FACTOR (*) = 1.5

# OF EQUIVALENT SINGLE AXLE 18-KIP WHEEL LOADS (*) = 0

   EQUIVALENT SINGLE AXLE 18-KIP LOADS
          20 YEAR DESIGN LIFE
   ***********************************

  CLASS    TYPE PVMT          EQUIVALENT
                              18-KIP LOAD*
  LIGHT    PARKING, CITY
           STREET, RURAL    22000-420000
           ROADS

  MEDIUM   SECONDARY        420000-3000000
           HIGHWAY

  HEAVY    INTERSTATE    3000000-10000000
           HIGHWAY

      * BASED ON 580.7 18-KIP LOADS PER
       1000 TRUCKS

(TO CONTINUE, PRESS SPACE BAR)
DO YOU WANT THIS LIST IN HARD COPY (0=NO, 1=YES)?  0
# OF EQUIVALENT SINGLE AXLE 18-KIP WHEEL LOADS (*) = 8500000

%%%%%%%%
TRIAL #1
%%%%%%%%

STRUCTURAL NUMBER =5.71

SPECIFY # OF LAYERS (MAX-10). 3

LAYER # FOR THICKNESS CALCULATION. 1
```

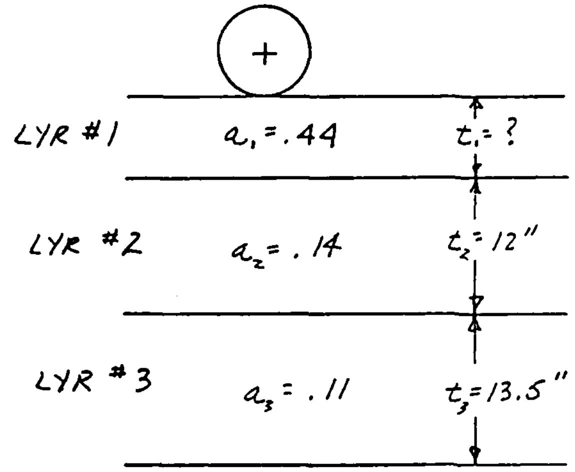
```
********************

LAYER #. 1

STRUCTURAL COEFFICIENT (*) = 0

    SELECTED STRUCTURAL COEFFICIENTS
    ********************************

 PAVEMENT COMPONENT         STR'L COEFF.
                          FLA   GA   MD   SC
  SURFACE COURSE
   ASPHALT CONCRETE .2-.4 .44* .44  .44

  BASE COURSE
   ASPHALT CONCRETE .2-.3 .30  .28  .34
   SAND-ASPHALT       -   .12  .28  .25
   SOIL-CEMENT       .22  .20  .28  .20
   GRADED AGGREGATE   -   .18  .14  .15
   CEMENT STABILIZED  -   .22  .28  .34
    GRADED AGGREGATE

  SUBBASE
   GRADED AGGREGATE   -   .14   -    -
   TOPSOIL OR SAND-   -   .10   -    -
    CLAY
       * MAXIMUM DEPTH OF 4.5 IN.

(TO CONTINUE, PRESS SPACE BAR)
DO YOU WANT LIST IN HARD COPY (0=NO, 1=YES)? 0
STRUCTURAL COEFFICIENT (*) = .44

********************

LAYER #. 2

STRUCTURAL COEFFICIENT (*) = .14

LAYER THICKNESS (INCHES) = 12

********************

LAYER #. 3

STRUCTURAL COEFFICIENT (*) = .11

LAYER THICKNESS (INCHES) = 13.5
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
AN EXAMPLE PROBLEM
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

TRIAL #1
********

LAYER          STR'L COEFF.    THICKNESS
  1            .44             5.8
  2            .14             12
  3            .11             13.5

STRUCTURAL NUMBER =5.71999994

EQUIVALENT SINGLE AXLE 18-KIP LOAD =8500000



SOIL SUPPORT VALUE =3

TERMINAL SERVICEABILITY INDEX =2.5

REGIONAL FACTOR =1.5
DO YOU WANT TO RUN ANY MORE TRIALS (0=NO, 1=YES)? 1


FOR A LAYER THICKNESS CALCULATION, TYPE(1); FOR AN 18-KIP LOADING CALCULATION, T
YPE(2). 2


HOW MANY TRIALS DO YOU WANT TO RUN? 1



SOIL SUPPORT VALUE (*) = 3


TERMINAL SERICEABILITY INDEX (*) = 2.5


REGIONAL FACTOR (*) = 1.5
```

%%%%%%%%
TRIAL #1
%%%%%%%%

```
SPECIFY # OF LAYERS (MAX-10) 3

********************

LAYER # =1

STRUCTURAL COEFFICIENT (*) =.44

LAYER THICKNESS (INCHES) = 5.8

********************

LAYER # =2

STRUCTURAL COEFFICIENT (*) =.14

LAYER THICKNESS (INCHES) = 12

********************

LAYER # =3

STRUCTURAL COEFFICIENT (*) =.11

LAYER THICKNESS (INCHES) = 13.5
```

```
%%%%%%%%%%%%%%%%%%%%%%%%
AN EXAMPLE PROBLEM
%%%%%%%%%%%%%%%%%%%%%%%%

TRIAL #1
********

LAYER              STR'L COEFF.     THICKNESS
   1               .44              5.8
   2               .14              12
   3               .11              13.5

STRUCTURAL NUMBER =5.717

EQUIVALENT SINGLE AXLE 18-KIP LOADS =8421531

SOIL SUPPORT VALUE =3

TERMINAL SERVICEABILITY INDEX =2.5

REGIONAL FACTOR =1.5
DO YOU WANT TO RUN ANY MORE TRIALS (0=NO, 1=YES)? 0

THANK YOU FOR USING AASHTO

BYE-BYE
```



SOIL SUPPORT VALUE = 3 (S_i)

TERMINAL SERVICEABILITY INDEX = 2.5 (p_t)

REGIONAL FACTOR = 1.5 (R)

E-18's = 8,500,000 (W_t)

$$\log W_t = 9.36 \log(SN+1) - .2 + \frac{G_t}{.4 + \frac{1094}{(SN+1)^{5.19}}} + \log\frac{1}{R}$$

$$+ .372\,(S_i - 3.0)$$

$$G_t = \log\left(\frac{4.2 - p_t}{2.7}\right)$$

TRY SN = 5.0

$$\log(W_t) = 9.36 \log(5+1) - .2 + \frac{\log\left(\frac{4.2-2.5}{2.7}\right)}{.4 + \frac{1094}{(5+1)^{5.19}}}$$

$$+ \log\frac{1}{1.5} + .372(3 - 3.0)$$

$$= 16.77 - .2 + \frac{-.46}{.500095} + (-.405) + 0$$

$$= 15.245$$

$$W_t = 4,177,296 \quad (E\text{-}18\text{'s})$$

TRY SN = 7.0

$$\log(W_t) = 9.36 \log(7+1) - .2 + \frac{\log\left(\frac{4.2-2.5}{2.7}\right)}{.4 + \frac{1094}{(7+1)^{5.19}}}$$

$$+ \log\frac{1}{1.5} + .372(3 - 3.0)$$

$$= 19.46 - .2 + \frac{-.46}{.4225} - .405$$

$$= 17.766$$

$$W_t = 51,971,497 \quad (E\text{-}18\text{'s})$$

TRY SN = 6.0

$$\log(W_t) = 9.36\,(6+1) - .2 + \frac{-.46}{.4 + \frac{1094}{(6+1)^{5.19}}} - .405$$

$$= 18.21 - .2 - 1.034 - .405$$

$$= 16.571$$

$$W_t = 15,732,371 \quad (E\text{-}18\text{'s})$$

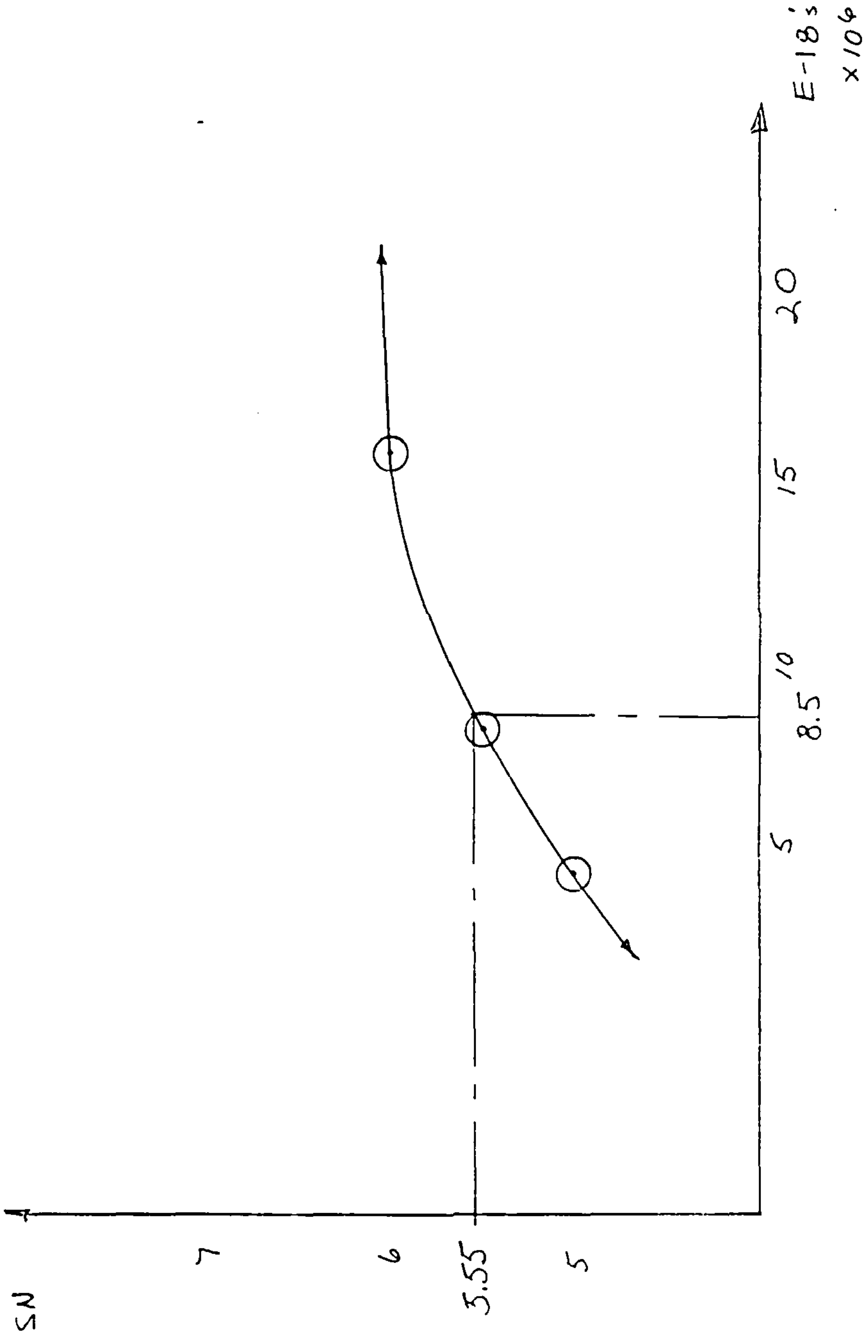
TRY SN = 5.5

$$\log(W_t) = 9.36 \lg(5.5+1) - .2 + \frac{-.46}{.4 + \frac{1094}{(5.5+1)^{5.19}}} - .405$$

$$= 17.52 - .2 + -.992 - .405$$

$$= 15.922$$

$$W_t = 8,219,300 \quad (E\text{-}18\text{'s})$$


SN
7
6
3.55
5
5
8.5
10
15
20
E-18's
x10^6

SN (HAND) = 5.55

SN (COMPUTER) = 5.72

* NOTE: DEVIATION DUE TO SI IFICANT FIGURES

$$SN = a_1(t_1) + a_2(t_2) + a_3(t_3)$$

$$t_1 = [SN - a_2(t_2) - a_3(t_3)] / a_1$$

$$= [5.55 - .14(12) - .11(13.5)] / .44$$

$$= 5.42'' \quad \text{(HAND SN)}$$

✓

$$t_1 = [5.72 - .14(12) - .11(13.5)] / .44$$

$$= 5.81'' \quad \text{(COMPUTER SN)}$$

✓

SECOND VERIFICATION PERFORMED BY PROGRAM. USING CALCULATED THICKNESS, CALCULATE E-18's.

INPUT	vs.	CALCULATED
8,500,000		8,421,531 ✓

5.8 Flexible Pavement Structure Design for Georgia

The following document details the requirements set forth by the Georgia Department of Transportation to divisional offices for the design of flexible pavements.

Flexible Pavement Structure Design for Georgia

Office of Road and Airport Design

Georgia Department of Transportation

District Design Personnel Conference

February 23, 1983

Table of Contents

Instructions for Using AASHTO Interim Guides for Pavement Structure Design in Georgia - Blank form on page number 6

1. Project Number

2. County

3. Description: Describe the project giving length, termini, number of lanes, new or existing location, widening and resurfacing, overlay, or any other significant information.

4. Type of Adjoining Pavement: Metal surface, bituminous surface treatment, asphaltic concrete, or P.C. concrete.

5. Traffic Data: Derive the mean traffic in VPD for one direction during the design period. The design period for Interstate and Primary projects is 20 years and for Secondary and other projects the design period is 15 years.

6. Design Loading: Distribute the mean AADT for one direction into the highest design lane traffic with a division between trucks and other vehicles. Use a truck classification of multiple units and single units if available. Use estimated lane distribution factors if the project is a multi-lane facility (page 7).

   Multiply the number of vehicles in each vehicle classification by an appropriate 18 kip single axle equivalent load (18^k S.A.E.L.) factor (page 8). The load factors may be derived as required for specific cases; i.e., a road leading to a pulpwood yard or a quarry.

   Sum the daily 18^k S.A.E.L. and multiply by the number of days in the design period to derive the total design period loading.

7. Design Data: Set the design terminal serviceability (P_t) at 2.5 for Class III or higher projects and 2.0 for Class IV or less projects. The soil support value is furnished in the soil survey but if a soil survey is not conducted the soil support value may be estimated in conjunction with the district soils engineer and the soil laboratory at Forest Park. The regional factor is also given in the soil survey but may be estimated from the attached chart if a soil survey is not conducted.

8. Recommended Flexible Pavement Structure: Enter the respective monograph for terminal serviceability of 2.0 or 2.5 with the soil support value, 18^k single axle equivalent loads and the regional factor to find the required weighted structural number of the pavement structure to be designed. This weighted structural number is then matched by a design structural humber which satisfies the equation $SN = a_1 d_1 + a_2 d_2 + a_3 d_3 + a_n d_n$ where a = structure layer coefficient and d = depth of each respective layer in inches. Engineering judgment and knowledge of local materials must be used to set depths and types of materials in the pavement structure; the district construction engineer, district materials engineer, or the state bituminous construction engineer should be consulted if required.

COMMITTEE ON ROADWAY PAVEMENT STRUCTURES

PROCEDURE FOR ESTABLISHING PAVEMENT STRUCTURE DESIGNS
FOR SECONDARY PROJECTS, AUTHORITY PROJECTS AND COUNTY CONTRACT PROJECTS

I. Secondary Projects

The procedure for making, processing, and reviewing these designs shall be as follows:

A. Projects Designed in District Offices

1. The Designs will generally be made for the District Engineer by his Design personnel in cooperation with the Assistant District Engineer, Pre-Construction and the District Materials Engineer.

2. The District Engineer shall transmit this design to the State Road and Airport Design Engineer listing the thickness and materials to be used in each layer of the pavement structure down through the subgrade stabilizer aggregate or select material, if these are required. The District Engineer shall also include information as to the availability of local materials used in the design, and the availability of alternate materials. This submission shall be made as early as possible in the plan development process.

3. The State Road and Airport Design Engineer shall check the design, reconcile any differences of opinion with the District Engineer and the State Materials and Research Engineer, and if the roadway is Class I or II, he shall submit the design to the Committee. If lower than Class II, the design need not be submitted to the Committee if concurred in by the State Road and Airport Design Engineer and the State Materials and Research Engineer.

4. After consideration by the Committee, the State Road and Airport Design Engineer shall inform the District Engineer that either the design is approved or that the Committee desires specific changes in the design, and that the approved or modified design may be used for the project plans.

5. If the District Engineer wishes to question modifications made by the Committee, he may do so through the State Road and Airport Design Engineer.

B. Projects Designed in the General Office

1. These designs shall be prepared in accord with policies of the Committee.

2. If these roadways are Class I or Class II, they shall be submitted to the Committee in regular manner.

3. If the roadway is lower than Class II, the design need not be submitted to the Committee if concurred in by the State Urban and Multi-Modal Design Engineer or the State Road and Airport Design Engineer (whichever has responsibility for the plans) and the State Materials and Research Engineer.

II. Authority Projects

A. When requested by the Director of Operations, the Committee will review and make recommendations concerning Authority Projects.

III. County Contract Projects

A. When requested by the Director of Operations, the Committee will review and make recommendations concerning county contract projects.

Approved by Committee

Chairman

PAVEMENT STRUCTURE DESIGN COMMITTEE

1. Consists of:

   State Highway Engineer - Chairman

   State Materials and Research Engineer - Secretary

   Director of Operations

   Director of Pre-Construction

   Director of Construction and
   State Construction Engineer

   State Road and Airport Design Engineer

   State Urban and Multi-Modal Design Engineer

   State Maintenance Engineer

   Project Review Engineer

   FHWA Representative

2. Reviews: All projects over 1000 VPD (future traffic) and any others requested.

3. Design Methods Approved:

   (A) Flexible Pavement

      (a) over 1000 VPD - AASHO Interim Guide
      (b) under 1000 VPD - generally use ultimate strength

   (B) Rigid Pavement AASHO Interim Guide

   (C) Overlay

      (1) Flexible over flexible

         (a) AASHO structural coefficients assigned

      (2) Flexible over rigid

         (a) AASHO structural coefficients assigned
         (b) Corps of Engineers
         (c) layered elastic theory

      (3) Rigid over flexible - AASHO Interim Guide

      (4) Rigid over rigid

         (a) Corps of Engineers
         (b) AASHO Interim Guide

The percent over-under design should be computed by dividing the difference between the weighted structural number and the total SN and dividing by the weighted structural number. The percent over-under design should be limited to about fifteen percent.

Any additional pertinent information should be entered under "remarks". The submission of the form should follow T. D. Moreland's instructions of January 6. 1970.

(Based on AASHO Interim Guide for the Design of Flexible Pavement Structures)

Project: ______________________ **County:** ____________

Description: ______________________

____

____

Type of Adjoining Pavement: **Beginning of Project:** ____________
End of Project: ____________

Traffic Data: 24 Hr. Truck Percentage ________
AADT Beginning of Design Period ____________ VPD ________ Year
AADT End of Design Period ____________ VPD ________ Year
Mean AADT (One Way) ____________ VPD

Design Loading:

Design Lane Traffic — 18k Axle Eq. Load

________________ x ________ = ________
________________ x ________ = ________
________________ x ________ = ________

Total Daily Loading: ________

Total Design Period Loading = ____________

Design Data: Serviceability (P_t) ________

(From Soil Survey) Soil Support Value (S) ________ Regional Factor (R) ________

Recommended Flexible Pavement Structure:

Type of Material	Thickness	Coefficient	SN

Weighted Structural Value (SN) (From Nomograph) = ________ Total SN = ________

Actual Design Life (Years) ________ Percent Over-Under Design ________

Remarks: ____________

Prepared By: ____________ Date

Submitted By: ____________ Date
District Pre-Construction Engineer

Recommended ____________ Date
State Road Design Engineer

Approved ____________ Date
Chairman, Committee on Roadway Pavement Structures

Approved ____________ Date
Commissioner

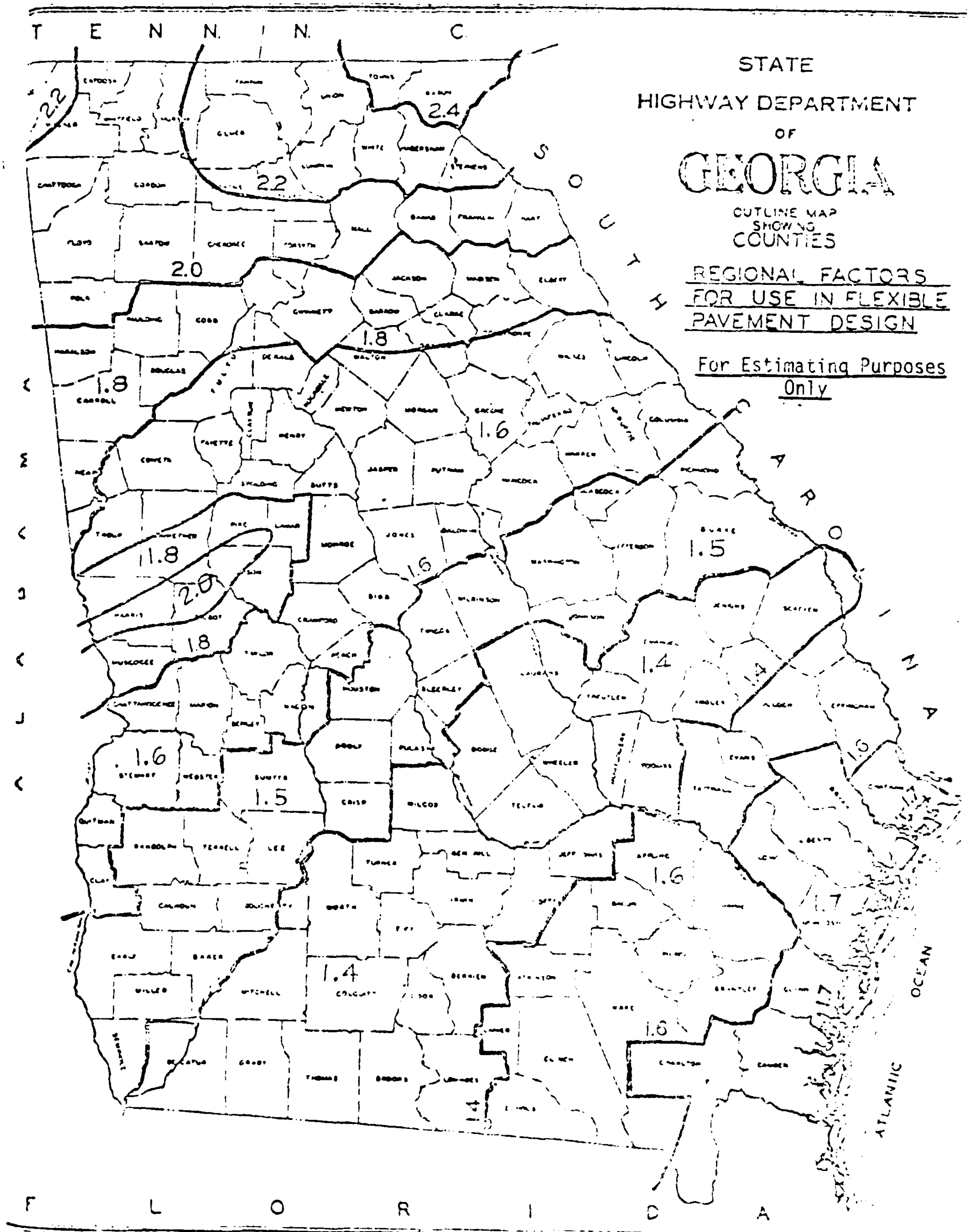
Table 4. Lane Distribution Factors.

FACILITY	Design Lane Distribution Factors - percent of One Way Trucks in the Heaviest Lane	
	Trucks	Other Vehicles
Four lane rural freeway	85-100	50-80
Four lane urban freeway	60-80	50-60
Six lane rural freeway	70	40-60
Six lane urban freeway	60	40-50
Four lane rural highway-free access	70-100	50-80
Four lane urban free access	60-80	50-60
Two lane highways and ramps	100	100

18^k Single Axle Equivalent Loads for Flexible Pavement

	Average 18^k S.A.E.L.
All Multiple Unit Trucks	1.4
5 Axle M.U. Trucks Only	1.7
4 Axle M.U. Trucks Only	1.1
3 Axle M.U. Trucks Only	0.9
All Single Unit Trucks	0.4
3 Axle S.U. Trucks Only	0.9
2 Axle S.U. Trucks Only	0.2

Facility	% M.U. Trucks	% S.U. Trucks	Average 18^k S.A.E.L. Flexible Pavement
Interstate Routes	100	0	1.4
	90	10	1.3
	80	20	1.2
Primary System Heavy State Routes	70	30	1.1
	60	40	1.0
	50	50	0.9
Medium State Routes	40	60	0.8
	30	70	0.7
	20	80	0.6
Light State Routes, Secondary System, City Streets	10	90	0.5
	0	100	0.4


STATE
HIGHWAY DEPARTMENT
OF
GEORGIA
OUTLINE MAP
SHOWING
COUNTIES
REGIONAL FACTORS
FOR USE IN FLEXIBLE
PAVEMENT DESIGN
For Estimating Purposes
Only
T E N N.
N. C.
SOUTH
CAROLINA
F L O R I D A
ATLANTIC
OCEAN
2.2
2.4
2.2
2.0
1.8
1.8
1.6
1.8
2.0
1.8
1.6
1.5
1.4
1.4
1.6
1.5
1.6
1.6
1.7
1.4
1.6
1.7
1.4

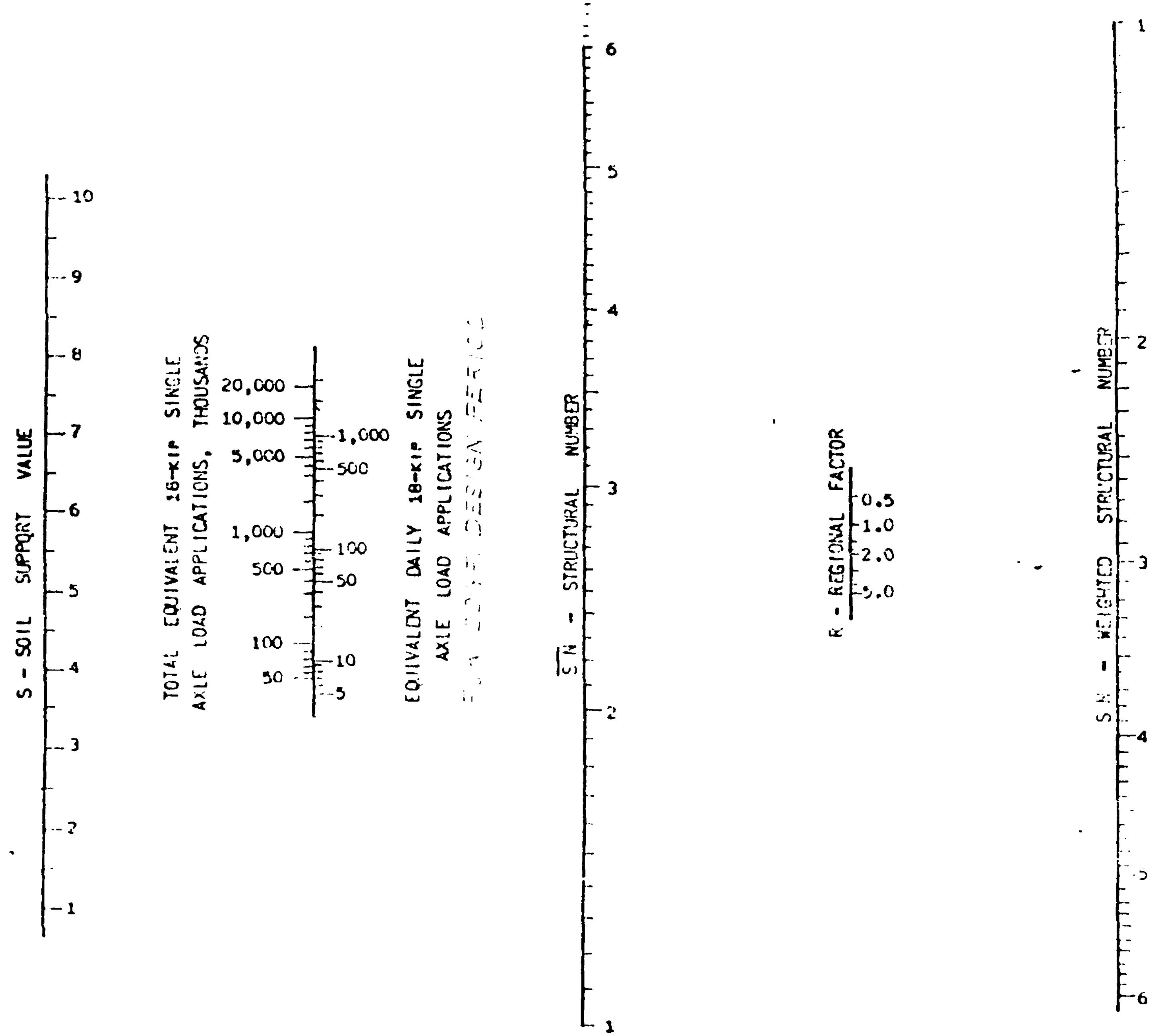


Figure 11-1 Design Chart for Flexible Pavements, $p_t = 2.5$

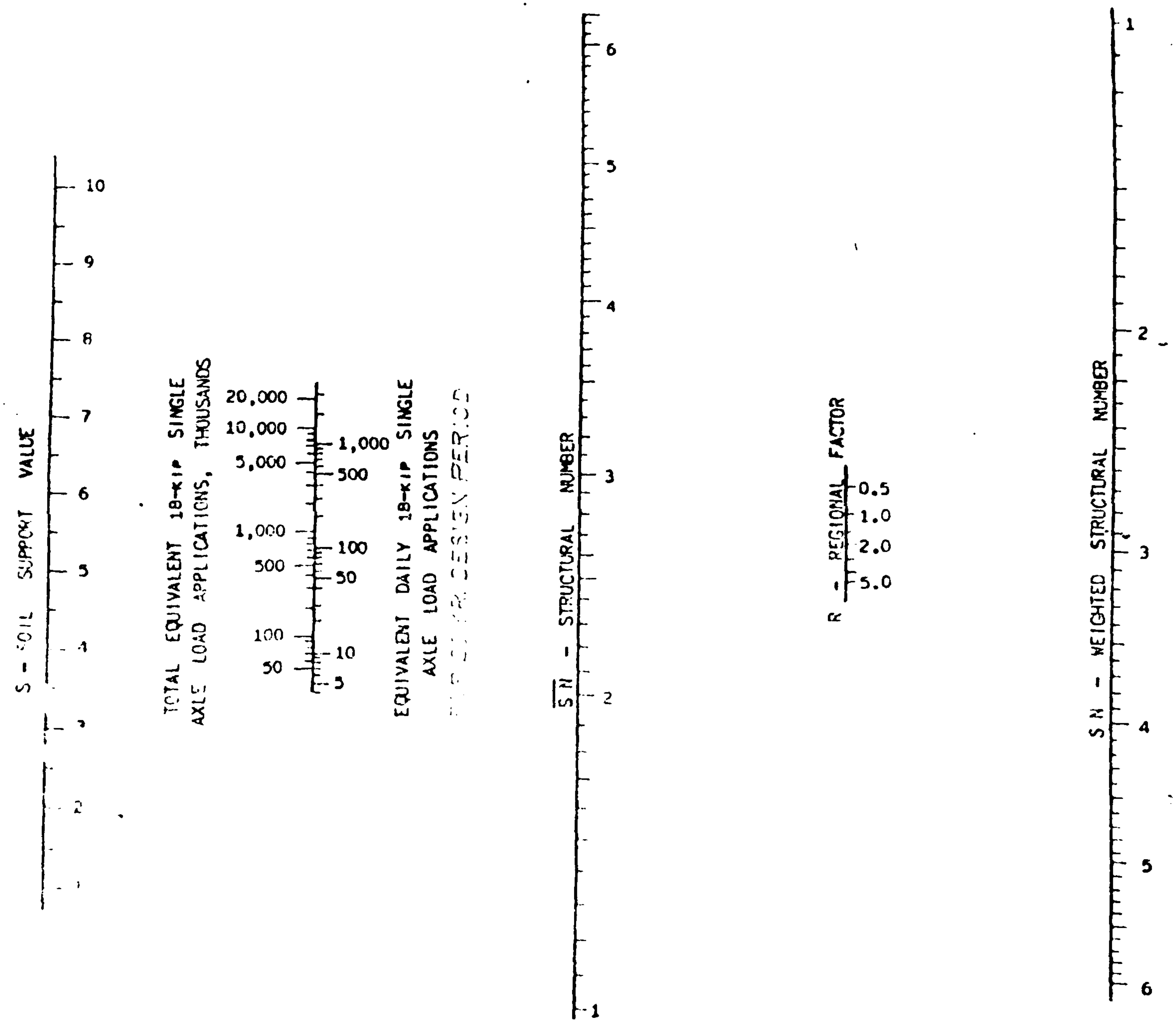


Figure II-2 Design Chart for Flexible Pavements p_t = 2.0

STRUCTURAL COEFFICIENTS FOR PAVEMENT DESIGN	Coef. Per Inch	APPLICABLE DEPTH BELOW SURFACE, INCHES
I. Surface Course'		0-4½
Asphaltic Concrete Surfacing and Binder	0.44	
II. Base Courses		4½-12
Asphaltic Concrete	0.30	
Graded Aggregate and Crushed Limestone (Compacted to modified density)	0.18	
Graded Aggregate and Crushed Limestone (Compacted to standard density)	0.14	
Topsoil or Sand Clay Bases	0.10	
Topsoil or Sand Clay (stabilized with (150 lbs./sq. yd. x 6" stabilizer aggregate)	0.12	
Cement Stabilized Graded Aggregate	0.22	
Soil-Cement	0.20	
Sand Bituminous	0.12	
III. Subbase Courses		Below 12
Graded Aggregate or Crushed Limestone	0.14	
Topsoil or Sand Clay	0.10	
Sandy Gravel (Float material which fails graded aggregate)	0.11	
Crushed Aggregate Subbase	0.10	
IV. Subgrade Courses		
Class I Soil	0.05	
Class II Soil	0.02	

FLEXIBLE PAVEMENT DESIGN ANALYSIS

(Based on AASHO Interim Guide for the Design of Flexible Pavement Structures)

Project: ______________________ **County:** ______________

Description: Two lane, from ~~~ to ~~~ , new location, length = 5.0 miles.

Type of Adjoining Pavement: Beginning of Project: asphaltic concrete
End of Project: asphaltic concrete

Traffic Data: 24 Hr. Truck Percentage 10%

AADT Beginning of Design Period 400 VPD 1975 Year
AADT End of Design Period 900 VPD 1990 Year
Mean AADT (One Way) $(400+900) \times \frac{1}{2} \times \frac{1}{2} = 325$ VPD

Design Loading:

Design Lane Traffic		18^k Axle Eq. Load		
325 VPD x 10% Trucks x 100% Lane Dist.=33 Trucks	x	0.4	=	13
325 VPD x 90% Other veh. x 100% L.D. = 293 o.v.	x	0.003	=	1
	x		=	

Total Daily Loading = 14

Total Design Period Loading = 14 x 365 x 15 years = 76650

Design Data: Serviceability (P_t) 2.0

(From Soil Survey) Soil Support Value (S) 3.0 Regional Factor (R) 1.8

Recommended Flexible Pavement Structure:

Type of Material	Thickness	Coefficient	SN
Asphaltic Concrete E	1½"	0.44	0.66
Asphaltic Concrete A or B	2"	0.44	0.88
Graded Aggregate	6"	0.18	1.08

Weighted Structural Value (SN) (From Nomograph) = 2.8 Total SN = 2.62

Actual Design Life (Years) 11 Percent ~~Over~~-Under Design $\frac{.18}{2.8} = 6$

Remarks:

Prepared By ______________________ ______ Date

Recommended ______________________ ______
State Road Design Engineer Date

Approved ______________________ ______
Chairman, Committee on Roadway Pavement Structures Date

Approved ______________________ ______

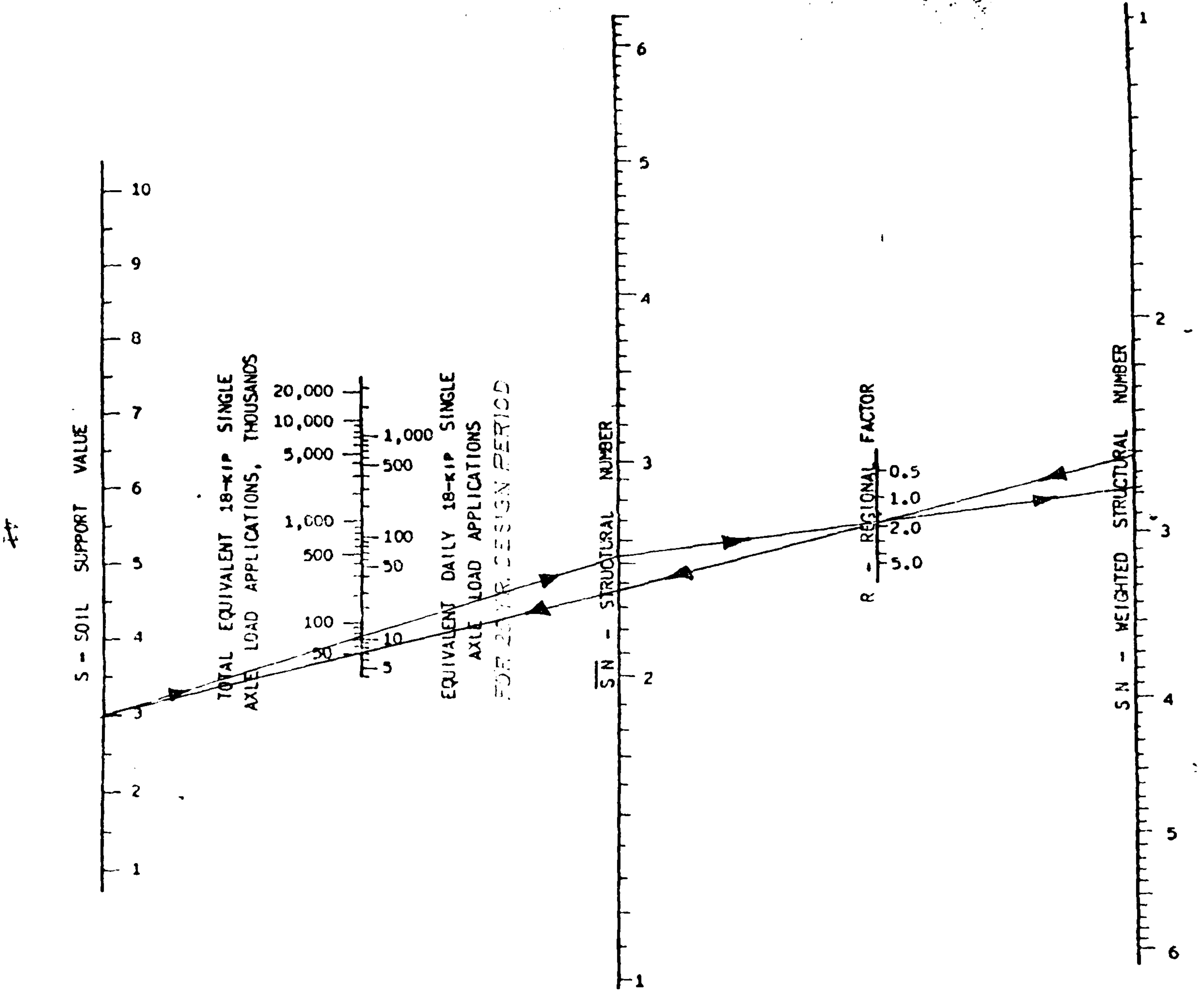


Figure II-2 Design Chart for Flexible Pavements, p = 2.0

Instructions For Using Ultimate Strength Pavement Structure Design In Georgia

Personnel other than those assigned to the Materials and Testing Laboratory are not authorized to design pavement structures using ultimate strength methods. Ultimate strength is used when a thinner pavement section is obtained than using the AASHTO Interim Guides. This normally occurs at below 1000 VPD with 10% trucks.

The method is based on using a design criteria of preventing shear failure by limiting the imposed vertical stress on the subgrade to a safe limit below the bearing capacity of the subgrade.

The steps in design area as follows:

1) Determine total loading.

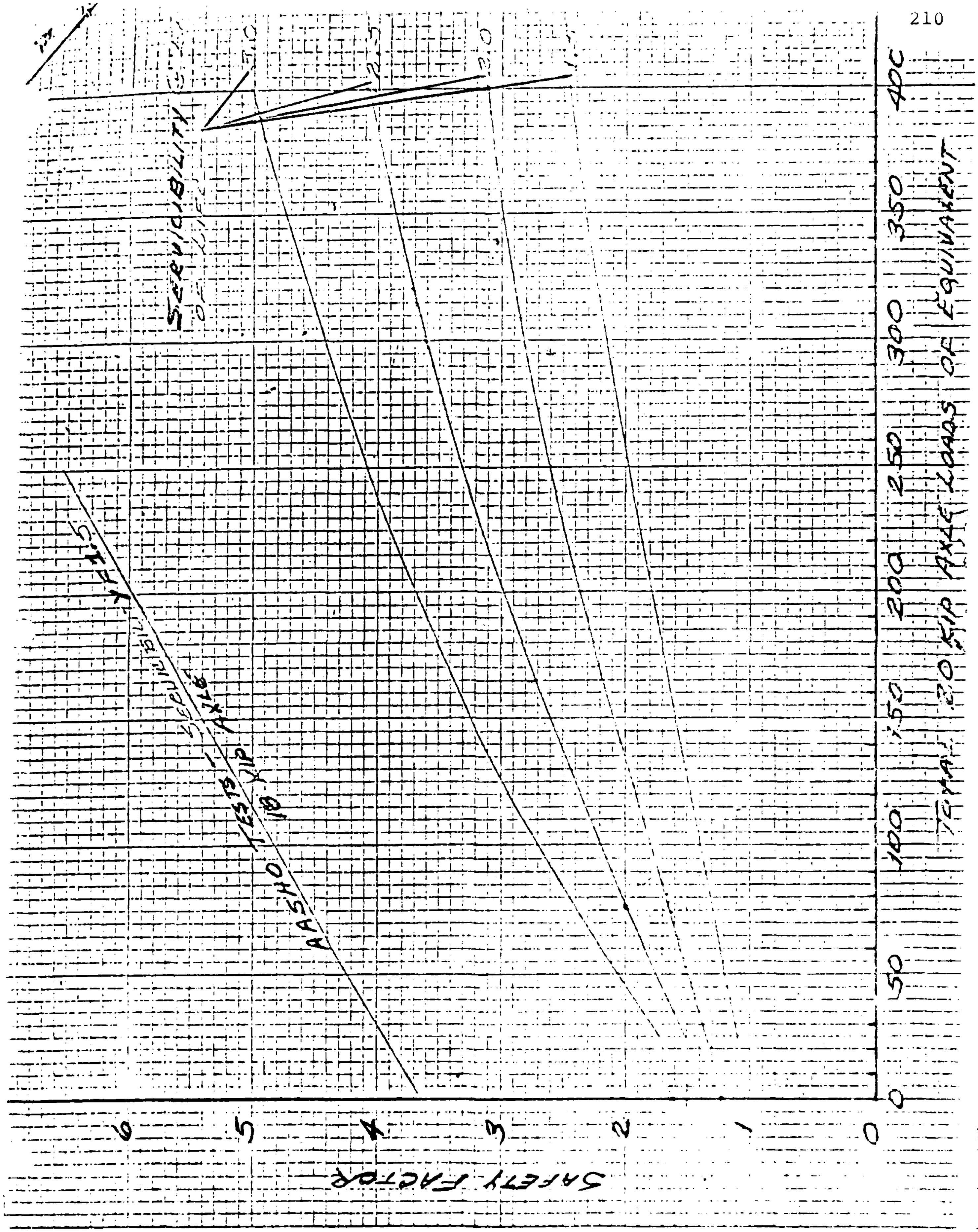
2) Obtain bearing capacity from the soils laboratory.

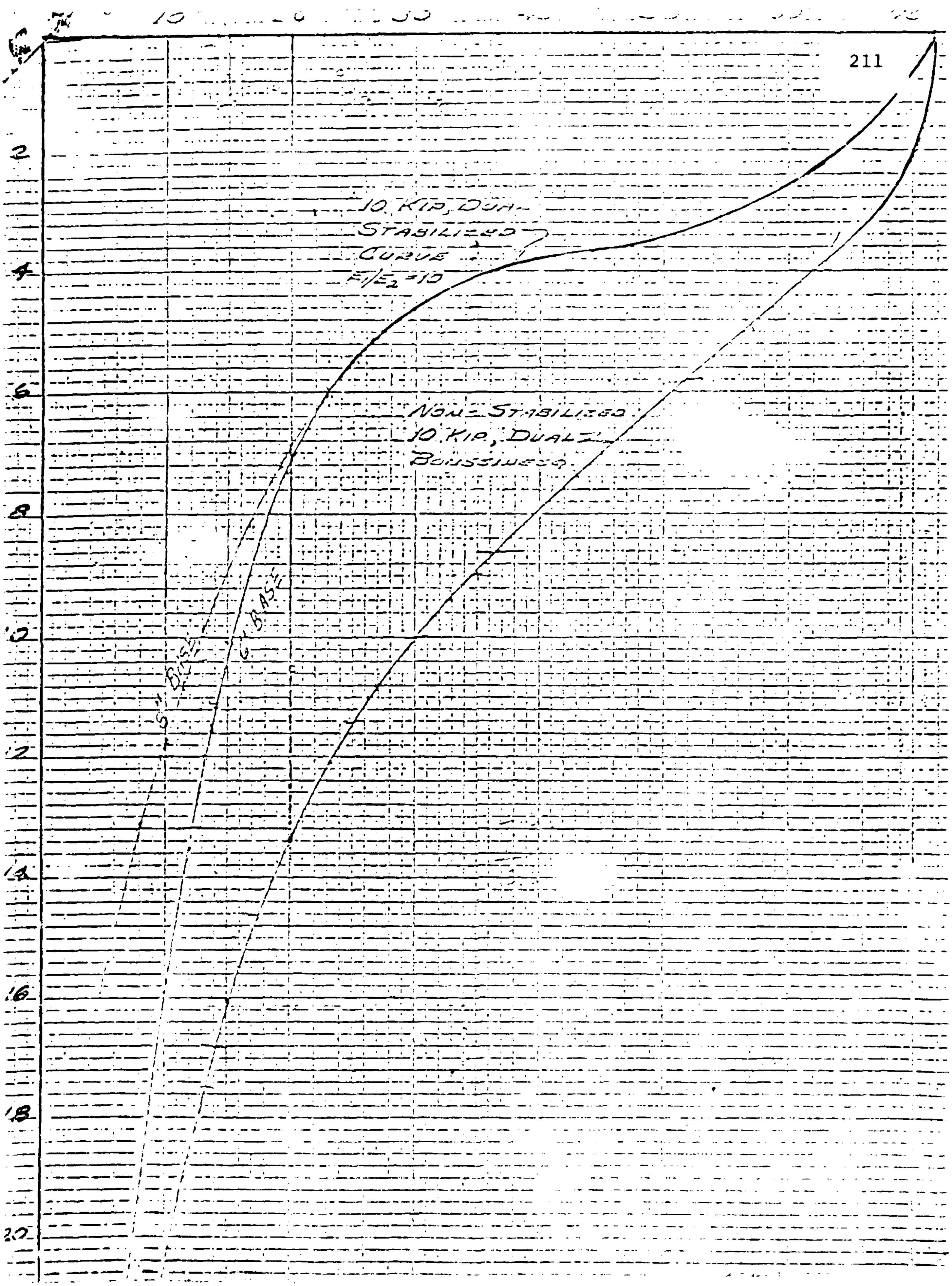
3) Determine the safety factor from page 19 .

4) Compute the safe bearing capacity = $\frac{\text{bearing capacity}}{\text{safety factor}}$.

5) Find total pavement thickness from page 20 .

6) Use engineering judgment and experience to set surface courses.


SERVICIBILITY
3.0
2.5
2.0
1.5
AASHO TESTS - 18 KIP AXLE
SF=1.5
SAFETY FACTOR
0
1
2
3
4
5
6
TOTAL 20 KIP AXLE LOADS OF EQUIVALENT
0
50
100
150
200
250
300
350
400


10 KIP, DUAL
STABILIZED
CURVE
$E_1/E_2 = 10$
NON-STABILIZED
10 KIP, DUAL
BOUSSINESQ
5" BASE
6" BASE
2
4
6
8
10
12
14
16
18
20

Ultimate Strength Sample Problem

1. Total Loading - Assume same as page 13

   Total Loading = 76,650 18^k S.A.E.L.

2. From soil survey - bearing capacity of subgrade soil = 31 psi

3. Set design terminal serviceability = 2.0

4. From page 19 - safety factor = 1.6

5. Allowable subgrade bearing capacity

   = bearing capacity of subgrade soil ÷ safety factor = 31 psi ÷ 1.6 = 19 psi

6. From page 20 - a) depth required for stabilized base = $7\frac{1}{2}$ inches

   use minimum design

   $1\frac{1}{2}$'' asphaltic concrete E

   2'' asphaltic concrete A or B

   6'' cement stabilized base

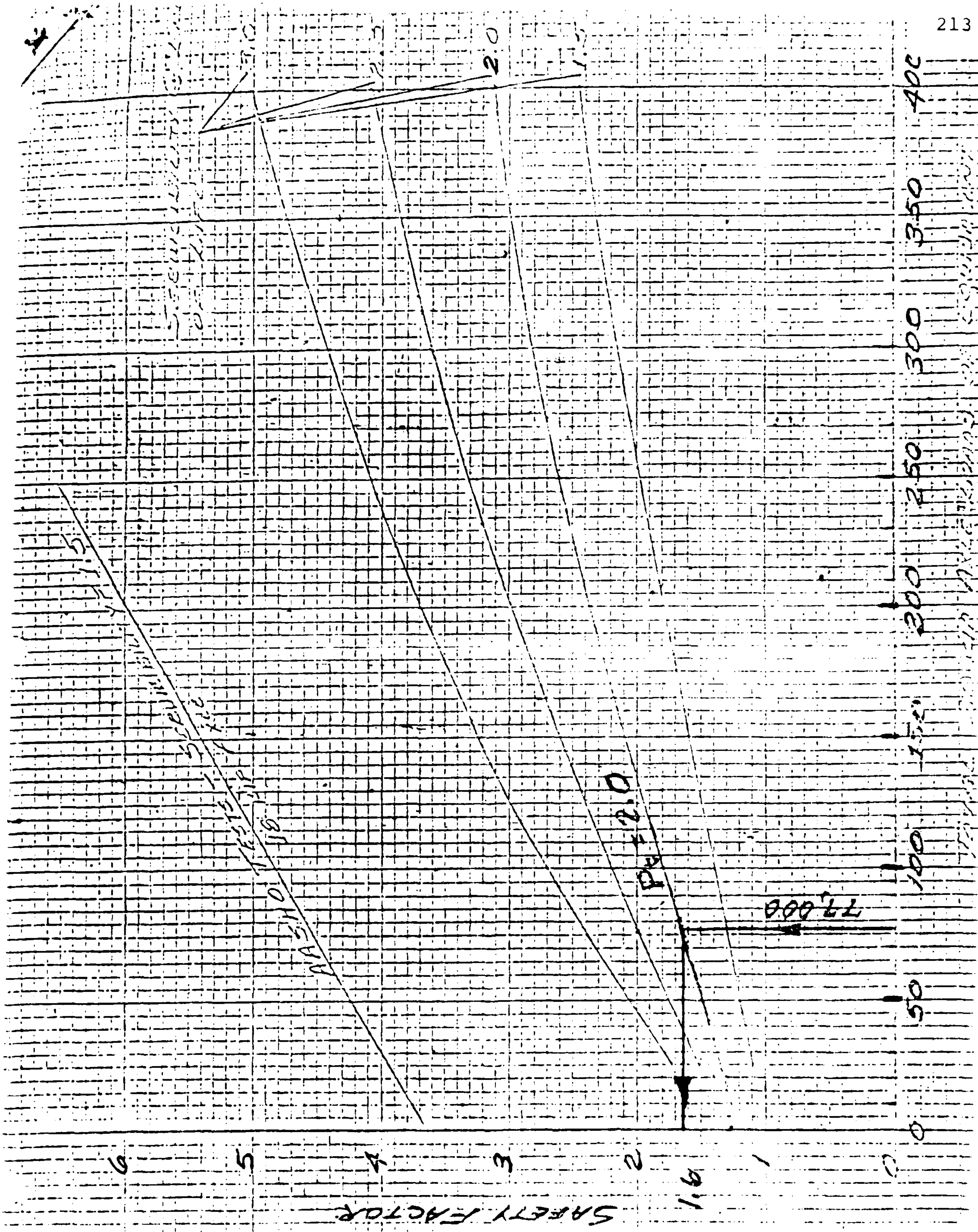
   b) depth required for non-stabilized base = $13\frac{1}{2}$ inches

   use $1\frac{1}{2}$'' asphaltic concrete E

   2'' asphaltic concrete A or B

   10'' graded aggregate

   c) cement treated base with thin surfacing acceptable


SAFETY FACTOR
0
1
1.6
2
3
4
5
6
0
50
100
150
200
250
300
350
400
72,000
Pc=2.0
2.0
1.5
AASHO TEST

5.9 References

1. AASHTO, "AASHTO Interim Guide for Design of Pavement Structures - 1972," Washington, D.C., 1972.

2. Ritter, L. J., and Paquette, R.J., Highway Engineering, Ronald Press Co., New York, 1967.

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CHAPTER VI

SUMMARY AND CONCLUSIONS

6.1 Scope

6.1.1 General

This report presents four programs designed to solve specific engineering problems. The report organization is based on the theme of a service that would be provided an engineering client acquiring engineering software. Each program is supported with background theory, programming rationale, and a user's guide; additionally, a program list, example problems, and hand verified solutions have been included.

The programs include the solution of the embedded post subject to lateral loads above grade (SIGNPOST 1), the solution of the cantilevered sheet pile wall (CANTWALL 1), the limit equilibrium analysis of slope stability by the Bishop method (BISHOP 1), and the design of flexible pavement based on the AASHTO Interim Guide, 1972 (AASHTO 1).

6.1.2 Hardware

Programming was performed on an Apple II-Plus personal computer with 64K storage. The programming language was Applesoft Basic operating on DOS 3.3. The programs were

stored on 5¼" disks. Peripheral equipment included two disk drives, a green screen monitor, and a thermal printer.

6.2 Personal Computers in Engineering Practice

Personal computers (PC) have become quite economical and extremely popular in the last five years. Businesses of all types rely upon PC's for processing routine data, storage and retrieval, word processing, cost accounting, and repetitive problem solving.

When General Electric introduced the first main frame computer (MACH I) in the early 1950's, computation speed was approximately three calculations per second. MACH I required 1500 ft^2 of floor space, a considerable air conditioning system, and constant maintenance replacing vacuum tubes. Today's PC requires six square feet of desk space, standard environmental controls, and a minimal maintenance program. Computation speeds range up to hundreds of calculations per second. Although technological advances have drastically increased the speed of main frame computing facilities, the size remains a physical constraint. Many businesses rely upon hard wire connections through telephone lines to utilize main frame computers. Costs include installation and maintenance fees as well as charges assessed on compilation and computing time.

A construction cost estimating service provided by McGraw-Hill Information Systems charges $300 to compile

a "quantity take off" for an average 20,000 ft^2, one floor office building. The cost of "time sharing" main frame computing facilities can be large and subsequently prohibitive for small businesses.

The principal advantage of the PC over main frame time sharing is its easy access and low relative cost. For accounting purposes, the purchase of a PC and software represent a one-time fixed cost. With exception of maintenance costs, the value of a PC is amortized through depreciation.

The absence of variable costs directly influence the cost of a service; consequently, bid prices or negotiated costs can be lower. Lower service costs directly influence the volume of services provided. Firms which utilize personal computers can maintain a sharp competitive edge.

As a result of increased personal computer use, the demand for software has become enormous. In response to this demand, hundreds of small software service companies have been formed. This is particularly evidenced by the advertisements in trade magazines and professional publications for software services. At this time, the demand appears to be almost limitless.

Many firms have been disappointed with the services provided when purchasing software packages. Although the actual programs are delivered as promised, the supporting documentation has left the user deserted and basically helpless. It is with this in mind that the author chose the

organization and theme of this report. The bulk of this text is devoted to educating the user about the programs use and limitations.

6.3 Program Applications

This section presents some classic applications for which the programs are best suited. Iteration of the background theory is avoided as each program is supported within its respective chapter. Typical applications of each Program are as follows:

6.3.1 SIGNPOST 1

a) Highway signs and markers subjected to wind loads

b) Pole-type buildings which resist wind loads through embedded post columns

c) Commercial signs and billboards subjected to wind loads

d) Utility poles (power and telephone) subjected to cable loads, guy wire loads, and wind loads

6.3.2 CANTWALL 1

a) Shallow excavation (<15'-20') when surface deflections are tolerable

b) Marine applications

6.3.3 BISHOP 1

a) Earth dams

b) Highway cuts and fills

c) Slopes near or under structures

d) Any slope whose failure can be approximated by a circular failure

6.3.4 AASHTO 1

a) Flexible pavement design

b) Analysis of existing pavement

c) Economic feasibility study

6.4 Recommendations for Future Work

The ultimate goal is to produce a program capable of solving a problem given an endless spectrum of varying conditions and parameters. Additionally, a program should be foolproof. Experience proves these goals serve as sound guidance but are impossible to totally achieve. Man-hour and computer memory constraints force programming efforts to be concentrated around specific tasks with definable end goals.

As with any program, the programs presented in this report can be improved. The limitations listed in each chapter can best serve as a basis for improvement.

6.4.1 SIGNPOST 1

The amelioration of this program might include a routine to compare the post diameter to the foundation volume (as a function of the required depth). The volume of a wood pole or of concrete is directly related to cost. The user could make an economic judgment as to the best diameter and depth of a foundation.

6.4.2 CANTWALL 1

This program can be enhanced by providing the ability to specify a surcharge above the upper soil. Soil layering at the option of the user would be desirable. A major improvement would be a routine to calculate the bending moment in the wall considering moment distribution. This could be complemented with a section modulus selection.

6.4.3 BISHOP 1

Enrichment of BISHOP 1 could include a search routine in which the minimum factor of safety is calculated without user intervention. Another improvement would increase the maximum number of points, lines, and soil types the user can specify.

6.4.4 AASHTO 1

AASHTO 1 could be ameliorated by providing two types of economic analysis. The first anlysis would contrast the use of alternate construction materials on a unit cost basis such as dollars per square yard of pavement. The second option would provide a life cycle cost analysis.

END

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